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RESERVOIR SEDIMENTATION IN THE SACRAMENTO-SAN JOAQUIN DRAINAGE BASINS, CALIFORNIA

By
Carl B. Brown
Sedimentation Specialist
and
Eldon M. Thorp
Geologist

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REPORT ON INVESTIGATIONS OF SEDIMENTATION IN RESERVOIRS IN THE SACRAMENTO-SAN JOAQUIN DRAINAGE BASINS, CALIFORNIA

Outline

SYLLABUS

This report contains the results of an investigation made to determine the effects of sedimentation on the useful life and on the plan of operation of the flood-control and multiple-purpose reservoirs proposed by the District Engineer, Corps of Engineers, War Department, in the comprehensive flood-control survey report on Sacramento-San Joaquin Basin streams, California, dated 1 February 1945.

Estimates of the effects of sedimentation on the proposed reservoirs have been based on surveys of sedimentation in 24 existing reservoirs, 20 of which were surveyed during the present study; on determination of the trap efficiency of 3 existing reservoirs and of the specific weight of deposited sediment in 12 existing reservoirs; and on reconnaissance conservation surveys covering approximately 13,000 square miles of drainage area. In addition, studies have been made of the distribution of sediment in existing reservoirs to provide a basis for predicting the distribution in proposed multiple-purpose reservoirs when plans of operation for these reservoirs are formulated. Factors that may influence future rates of sedimentation in the proposed reservoirs have been considered and are discussed at some length.

It has been concluded that capacity losses as a result of sedimentation in the proposed reservoirs during the first 50 years after their construction will range from as little as 0.3 percent to a maximum of 11.3 percent, and that the reservoirs will retain at least 50 percent of their capacity from a minimum of 200 years to a maximum of 8,700 years. It is further concluded that the rates of sedimentation will be so low that they need not be considered a determining factor in the total capacity to be provided, in the allocation of capacity to various uses in the multiple-purpose reservoirs, or in determining the plan of operation of any reservoir during the first 50 years of its life. It is concluded, however, that sedimentation should be taken into account in designing the outlet works to be installed in the six reservoirs proposed solely for flood control. Furthermore, it is pointed out that sedimentation will cause calculable damages to the proposed reservoirs from the beginning of storage, even though all projects will have a long, useful life. The damages resulting from capacity loss justify certain costs for sedimentation-control measures, but consideration of these costs and benefits has not been included within the scope of the present investigation.

The low rates of sedimentation and the negligible effects on reservoir design and operation in this area, as compared with many other sections of the United States, are attributable to two factors: (1) The prevailingly low rates of sediment production from the contributing drainage areas, estimated to range from 230 to 940 tons per square mile annually, or 0.11 to 0.70 acre-foot per square mile annually, and (2) the relatively large ratios of storage capacity to drainage area, which result in low rates of storage depletion per

unit of sediment inflow. Rates of sediment inflow or sediment production from the drainage areas above the proposed reservoirs are only 5 to 20 percent of those determined for many other drainage areas in California and throughout western United States.

INTRODUCTION

This report presents the results of an investigation of reservoir sedimentation in the Sacramento and San Joaquin River drainage basins, California. The objective of the investigation was to determine the effect of sedimentation on the design, operation, and useful life of the proposed flood-control and multiple-purpose reservoirs described in the Comprehensive Flood Control Survey Report on Sacramento-San Joaquin Basin Streams, California, by the Sacramento District, Corps of Engineers, War Department, Sacramento, California, dated 1 February 1945. The investigation was carried out by the Sedimentation Section, Soil Conservation Service, U. S. Department of Agriculture, at the request of the District Engineer, Sacramento District, Corps of Engineers, under the authority of the Flood Control Act of June 22, 1936 (Public Law No. 738) as subsequently amended. Most of the costs of technical supervision and certain other specialized services were reimbursed to the Soil Conservation Service by the Engineer Office. The Engineer Office furnished field parties for reservoir surveys and provided for all office engineering work, transportation, and other facilities. Field investigations were started in May 1945 and were finished in June 1946.

ACKNOWLEDGMENTS

Many Federal, State, and local officials and individuals aided in the conduct of these investigations. Valuable data and advice were furnished by John H. Lawrence and T. R. Littlefield of the Regional Office, U. S. Forest Service, San Francisco; W. H. Holmes, Supervisor of Dams, State of California; R. L. Egenhoff, engineer of the California Debris Commission; L. Standish Hall, engineer of the East Bay Municipal Utilities District, Oakland; Engineering Division personnel of the Pacific Gas and Electric Company; officials of the Orland project, U. S. Bureau of Reclamation; and officials of various privately owned irrigation districts, and owners of privately owned reservoirs.

The Sacramento District Engineer Office cooperated to the fullest extent in assuring the successful completion of these investigations, particularly by supplying field survey parties, transportation and equipment, office facilities, and drafting and engineering services. Administrative arrangements for the project were made by Frank Kochis, Chief, Engineering Division, and F. G. Christian, Chief, Planning Branch. Walter J. Parsons, Jr., Chief, Hydrology Section, was particularly helpful in reviewing and aiding in the technical aspects of the investigation. Much of the office engineering work was done by C. C. Osborne. Acknowledgment is made to various officials of the Soil Conservation Service for their cooperation with the writers,

especially to John S. Barnes, State Conservationist, who assisted in administrative arrangements; to D. A. Carey and Kenneth Croeni, who made the reconnaissance drainage area surveys under the supervision of Leonard Wohletz, State Soils Scientist; to Louis M. Glymph, Jr., who was in charge of the earlier phases of the field investigations for the Soil Conservation Service; and to H. A. Einstein for analysis of bed-load movement on Dry Creek.

PURPOSE AND SCOPE

The purpose of this investigation was to obtain the basic data necessary for estimating the rates of sedimentation in the flood-control and multiple-purpose reservoirs proposed for construction by the Corps of Engineers in the Sacramento and San Joaquin drainage basins. In addition to estimating the total quantity of sediment that might be expected to reach each of these reservoirs during certain periods following their construction, studies were made to furnish a basis for estimating the probable distribution of sediment within the storage space allotted to power, irrigation, and flood control in the multiple-purpose reservoirs. Also, the percentage of sediment that would pass through or over the dams was estimated. These data provide a basis for determining any allowance that should be made for sedimentation in the design of reservoirs, and for developing a long-range operation schedule to take account of storage depletions. Furthermore, they give a measure of the probable useful life of the reservoirs.

The estimates for the proposed reservoirs are based on measured rates of sedimentation in 24 reservoirs, of which 20 were surveyed during this investigation; on determinations of specific weight and composition of sediment in 12 reservoirs; on determination of trap efficiency of 3 reservoirs; on reconnaissance mapping of physical land factors on about 13,000 square miles, including the drainage areas of all surveyed reservoirs and all those proposed reservoirs that are now authorized for construction; and on analysis of existing geologic, hydrologic, and other data.

The specific area investigated is confined to the Sacramento-San Joaquin-Tulare Lake Basins. Areas not included in the investigation were the Tehachapi Range, the Coast Range section on the southwest side of the San Joaquin Basin, the Diablo Range, the southern tip of the northern Coast Range, and the drainage areas above Shasta Dam.

It has been recognized for many years that sedimentation in storage and flood-detention reservoirs may be a threat to the economic life of such projects and may require changes in operating procedures as the capacity is depleted. Knowledge of the expected rates of sedimentation in advance of construction may justify changes in design to increase the life and operating efficiency of the reservoir. The economic effects of sedimentation may also justify erosion-control measures on drainage areas to reduce the rates of sediment production.

Virtually no quantitatively reliable data on rates of sediment production in the Sacramento and San Joaquin were available prior to this investigation. Reservoir surveys in some other sections of California had previously shown high rates of sediment production and critical losses of capacity in flood-control, irrigation, water-supply, and multiple-purpose reservoirs. Thirteen flood-control and water-conservation reservoirs constructed by the Los Angeles County Flood Control District had capacity losses ranging from 3 to 83 percent by 1940 in periods of 1 to 20 years*. The Brown Canyon barrier, constructed by the Forest Service on the Arroyo Seco, Los Angeles County, in 1942, lost more than 20 percent of its estimated debris storage capacity in the flood of January 1943, the first year after construction(2)**. This was equivalent to a sediment production of more than 10 acre-feet per square mile from the 14.8-square-mile, steep, mountainous drainage area during this one flood. The average annual rate of sediment production for the mountainous portion of the Arroyo Seco as shown by a 21-year record (1920-1941) of accumulation in Devils Gate Reservoir is approximately 3.8 acre-feet per square mile*. Being the longest record in the country, this may be close to the average for all drainage areas controlled by dams of the Los Angeles County Flood Control District. Measured rates, however, range from 0.65 to 9.7 acre-feet per square mile annually.

Morena Reservoir, one of the larger municipal water-supply reservoirs of San Diego, California, lost 10.5 percent of its capacity between 1910 and 1935, which was equivalent to a sediment production of 2.56 acre-feet per square mile of drainage area(1). Gibraltar Reservoir, the municipally owned water-supply reservoir of Santa Barbara, California, lost 46.4 percent of its capacity in 24 years (1920-1944) and showed an annual sediment-production rate (including above-crest deposits) of approximately 1.9 acre-feet per square mile***. Little Rock Reservoir, constructed for irrigation by the Palmdale-Little Rock Irrigation District, on the Mojave side of the San Gabriel Range, Los Angeles County, lost 19.28 percent of its capacity in 19 years (1924-1943) and showed an annual sediment-production rate of 0.63 acre-foot per square mile(5).

In the San Francisco Bay area high rates of sediment production have been shown by surveys of the following reservoirs of the East Bay Municipal Utilities District(10): Chabot, 1.3 acre-feet per square mile (1875-1942); Upper San Leandro, 1.9 acre-feet per square mile (1924-1941); San Pablo, 2.0 acre-feet per square mile (1917-1943); Temescal, 1.7 acre-feet per square mile (1869-1907).

In his classic studies of hydraulic-mining debris in the Sierra Nevada, G. K. Gilbert(9) estimated an average annual sediment production of 0.45 acre-foot per square mile from all sources (including mining

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* Computed from data obtained from the Los Angeles County Flood Control District.

** References are given on pages 68-69.

*** Computed from data obtained from City of Santa Barbara.

debris) from the entire Sacramento area during the 65-year period, 1849-1914. Of this total he estimated that 0.23 acre-foot per square mile reached tidewater at the mouth of the Sacramento River. In more detailed estimates for the Yuba River drainage basin, where extensive hydraulic mining had been carried on in previous years, Gilbert estimated an average annual sediment-production rate of 7.3 acre-feet per square mile for the 60-year period, 1849-1909. Of this amount, he estimated that 0.33 acre-foot came from soil erosion, roads, and natural sources, and the remainder from mining activities. He further estimated that the annual rate had dropped to 3.7 acre-feet per square mile by 1905 because of cessation of hydraulic mining some years previously.

The present investigation was decided upon in the light of the following facts:

1. Reservoir surveys in other sections of California and the West had shown high rates of sediment production and rapid losses of reservoir storage capacity that would seriously impair services and require changes in operating procedures within 50 years after construction.

2. Gilbert's investigations showed continuance of high rates of sediment production in 1905 in some major tributaries of the Sacramento River Basin as a continuing effect from hydraulic mining in former years.

3. Almost no reliable recent data existed on rates of sediment production from the mountainous drainage areas tributary to the Sacramento and San Joaquin Basins.

4. A very large investment in flood-control and multiple-purpose reservoirs is proposed in the comprehensive plan of the Corps of Engineers.

PHYSICAL CHARACTERISTICS OF THE AREA

A comprehensive description of the physical characteristics of the Sacramento-San Joaquin Basin is given in House Document No. 191, 73d Congress, 2d Session, Washington, 1934.

These descriptions are amplified in the Comprehensive Flood Control Survey Report on Sacramento-San Joaquin Basin Streams, California, Sacramento District, Corps of Engineers, Sacramento, California, dated 1 February 1945. A list of prior reports on the area is given on page 2 of that report. Extent of the area covered by sedimentation studies is indicated in Figure 1.

Certain physical characteristics of this area that influence rates of sediment production merit review and emphasis.

Topography

The broad, low-lying Sacramento-San Joaquin Basin is flanked on the east side by the high Sierra Nevada; on the west by the Northern and Southern Coast Ranges, which are in turn separated by an arm of San Francisco Bay; on the north by the Trinity Mountains and Cascade Range; on the south by the Tehachapi Mountains. Most of the proposed flood-control and multiple-purpose reservoirs lie on the western slope of the Sierra Nevada, or on the eastern slope of the North Coast Ranges. The drainage areas range in elevation from approximately 500 feet to 14,000 feet in the southern part of the eastern San Joaquin Basin, and from 300 feet to 9,000 feet in the middle and northern parts of the San Joaquin Basin. Reservoirs proposed for the eastern Sacramento Basin have drainage areas ranging in elevation from about 400 to 7,000 feet. The drainage areas of reservoirs to be located on the valley floor range from approximately 100 feet to 2,500 feet in elevation. Table 1 shows the mean elevation of each drainage area considered in this report. Mean elevation as used here is the elevation at which 50 percent of the reservoir drainage area is lower and 50 percent is higher. Land slopes above the 1,000-foot contour are consistently steep in all drainage areas. Stream gradients range from about 40 to 350 feet per mile above the 1,500-foot altitude, and from about 1 to 45 feet per mile below 1,500 feet. Most of the drainage areas may be appropriately described as rough to broken, steep to precipitous, rocky, mountainous terrain.

Climate

Summer and winter seasons are well defined. The valley floor has long, hot, and dry summers with relatively short, mild, and moderately wet winters. The mountainous portions above the 3,000-foot altitude are moderately hot and dry during summer. In an average year the range in minimum temperatures in winter is from about -5° F. at the highest altitudes to about 20° F. at 3,000 feet. The entire mountain area is subject to prolonged heavy rainfall or snowfall in sharply defined storms. Annual precipitation is as indicated by isohyetals on Figure 1.

Runoff

Because of the wide range in elevation within the basin, the runoff consists of two general types - that from heavy rainfall on moderate to low elevations and that from melting snow at higher elevations at the end of the winter season. Runoff from rainfall occurs mainly from November to March. This is the season during which most of the erosion takes place and most of the sediment is transported to the reservoirs. Further, since runoff from rainfall comes principally from altitudes below 6,000 feet, it is most likely to entrain sediment from soils and rocks of relatively high erodibility. Much of the surface of the higher altitude country, which receives snow instead of rain during the winter months, consists of resistant granite and other hard rocks that yield little sediment. Falling snow produces no sheet erosion, and its melting is

generally at such moderate rates that comparatively little sediment is carried into stream channels. The principal sources of sediment from snow-melt water are the stream banks and channels.

The long, hot, and dry summers prepare the soils for rapid erosion by the early winter rains. By the end of summer the surface soil is powdery, the vegetal cover has decreased to a minimum, and more soil is exposed as a result of cultural activities, such as seasonal farming, grazing, lumbering, road building, and mining. The reversal of these unfavorable conditions is not possible until the soils are moistened and vegetation has revived.

Flood and Drought History

It is probable that the great bulk of sediment from mountain drainage areas is eroded and transported during the large cyclonic storms. A relatively high proportion of the total sediment load is bed-load material such as sand and gravel. Most of those existing reservoirs in which sediment was measured have been constructed since 1905. The records obtained from them represent the integration of sediment transportation in the flood years since then. Large general floods affecting most or all the Sacramento-San Joaquin Basin since 1905 occurred in March 1907, January-February 1911, January 1914, December 1937, February-March 1940, January and March 1943, and February 1945. Large floods affecting only a part of the Basin occurred in January 1909, March 1911, January 1914, January 1916, February 1917, February 1919, February 1922, February 1927, December 1931, February 1937, and March 1938. From these records it would appear that maximum erosion and sediment transportation occurs from December to March, or during about 30 percent of the year. Furthermore, the flood events are fairly well distributed through the period of sedimentation records. Drought records are less indicative of the quantity of sediment transported, although the major floods that follow an abnormally dry season may entrain more than usual amounts of sediment from the land. Dry seasons prevailed in 1912-1913, 1924, and 1930-1934.

Geology and Soils

The Sacramento-San Joaquin Valley is a vast trough of alluvial sediments. Geologically these are young, generally unconsolidated, and are potentially a prolific source of sediment for stream transportation. The land slopes are gentle, however, and stream gradients are very low compared with the surrounding mountain areas. Consequently, the sediment-transporting capacity of the streams is not large, and the Valley is predominantly an area of deposition rather than erosion. Only on the steeper slopes of the older terrace deposits on the sides of the Valley is erosion producing relatively greater quantities of sediment than in the mountain areas.

Flanking the eastern side of the Valley trough is the great uplifted block of the Sierra Nevada. The core of this uplift is chiefly granite

and other acidic intrusive rocks. These are exposed at most of the higher elevations, particularly above 5,000 feet. The foothill areas bordering the granite consist largely of metamorphic rocks which are covered by a shallow but distinct soil mantle. The Cascade and Trinity Mountains on the north are also largely of granitic origin with minor areas of recent lava flows. The Coast Ranges on the west side of the Sacramento Valley consist of sedimentary sandstones and shales, and metamorphosed cherts, slates, and schists.

The bulk of the exposed granite yields very little sediment, but soils developed on granite at altitudes below 6,000 feet usually have a high erosion potential. These soils are commonly shallow, however, and are generally well protected by vegetation. Hence, the actual rates of sediment production per unit area are low. Locally the granites of the Trinity Mountains northeast of Redding are decomposed to a considerable depth. Where unprotected, these yield readily both to surface erosion and to stream cutting; they produce considerable quantities of sand and gravel. Granite areas in the Sierra Nevada south of the Merced River are less resistant to erosion than those to the north, and soils overlying this granite are deeper and more erodible.

The metamorphosed rocks of the Sierra Nevada foothills vary considerably in their erodibility, but in general are not highly productive of sediment. However, the soils developed on them, particularly those having light textures, are often very erodible. Sedimentary and metamorphic formations and the soils overlying them in the northern Coast Range are moderate sediment producers.

Vegetal Cover

The floor of the Great Valley in its native state was covered by greasewood and marsh grass in the lower, more alkaline or swampy parts near the valley axis and by bunch-grass types on the lower terraces [17]. Along the streams were scattered groves of live oak and valley oak. As a result of overgrazing, native grasses in many areas have been replaced by less desirable annual grasses and weeds. Much of the flatter areas of original grassland have been plowed for crop and orchard use.

In the lower foothills between the grassland of the Valley and the forest stand of the mountains is a belt of chaparral, which is a mixed forest growth of stunted hardwood trees and shrubs. Characteristic of the lower part of this belt are open groves of oaks scattered over a desert-type grassland. The live oak-savanna is succeeded in the upper part of the belt by a denser shrub cover of manzanita, wild lilac, and oak brush.

Above the chaparral belt is a forest belt containing predominantly yellow pine, sugar pine, and incense cedar. White fir is not uncommon. This forest varies in composition according to altitude, moisture, and exposure, so that several fairly distinct types are evident. On moderately

dry, western slopes, and especially on soils of serpentine formation on the western slope of the Sierras, the most prevalent type of forest is western yellow pine and incense cedar. Under the same conditions of temperature and soil, but at an elevation of 3,500 to 5,500 on the western slope of the Sierras, it is yellow pine and sugar pine.

Above the pine belt is a spruce-fir forest. In the Sierras this belt includes several types. On cool meadows with plenty of moisture, ranging in elevation from 5,500 to 6,500 feet, it is characterized by pure stands of lodgepole pine. From 7,000 feet to timberline it is made up of alpine fir and mountain hemlock. On the northerly and northeasterly slopes in the Sierras at an elevation of about 6,000 feet, it is largely composed of pure red fir. In most of these stands there are open parks and stream-side meadows that provide excellent summer grazing. This belt is usually subject to heavy snowfall, and has a mean annual precipitation of more than 30 inches. Temperatures are relatively low both in summer and winter.

At the highest elevations above timberline occurs the alpine meadow, covered by grasses and sedges with many low-growing, flowery plants. Here also are the great rock fields, which have only cliff plants and lichen, and the snow fields and glaciers, which are devoid of vegetation.

Land Use and Erosion

The principal cultural factors affecting sediment production are:

Agriculture. Approximately 21 percent of the Sacramento-San Joaquin Basin is used for agriculture. Most of the agricultural land lies on the valley floor. A small part lying in the foothills and upland valleys, however, is probably the source of most of the erosion attributable to agricultural activity. Drainage areas mapped for sediment production indicate a relatively high rate of soil erosion where bad agricultural practices prevail.

The principal kinds of accelerated soil erosion which may be attributed to agriculture are sheet, gully, and stream-channel erosion. Each may be produced by bad tillage practices, overgrazing, clearing of over-steep lands, or unsound ditching and farm road-building methods.

Overgrazing has caused reduction and almost complete loss of vegetal cover in some areas, especially west of the Sacramento River between Black Butte and Paskenta. Furthermore, the resulting replacement of the native bunch-grass by annual grass-weed types has materially lowered resistance to erosion. Overgrazing is also conspicuous in the southeastern San Joaquin Valley. The end result of overgrazing is severe sheet erosion and gullying, which often develops in the trails made by range animals.

Mining activity is now much less than in the period 1850-1900. During this half-century, hydraulic and placer mining for gold in the Sacramento-San Joaquin Basin reached the greatest volume ever attained in any country. Despite the decline since 1900, mining is still a major industry in the Basin and, as such, is potentially one of the greatest sources of sediment if it should be carried on without proper safeguards. The vast quantities of mining debris put into the streams during the 19th century caused widespread damage by clogging stream channels and depositing sterile sediments on fertile agricultural valley lands. Much information on rates and distribution of sediment derived from earlier hydraulic mining is given by Gilbert(9). Although most of the old debris has passed down the stream system, there is still considerable bed-load gravel derived from mining in the lower reaches of the American, Bear, and Yuba Rivers, and some in other large streams. These lag deposits are nearly stabilized and are moved in quantity only by the largest floods. Their volume and probable rate of movement indicate that they are now a minor source of the total sediment.

Hydraulic mining scars cover relatively large areas of land in the Bear, American, and South Yuba drainage basins. They also occupy smaller areas in other drainage areas. Some are contributing sediment to the streams, but much of the debris eroded from the walls and slopes is lodging at the base of slopes and in the mining pits. Although at first observation these scars give the impression of furnishing a large amount of damaging sediment, field investigations indicate that the quantity supplied is moderate to small.

Dredging of virgin gravel terraces puts considerable silt and clay into suspension in the stream flow. Although the gravels are transported slowly, if at all, the dredging in larger permanent streams sets free the finer particles of sediment which are then carried by stream flow to downstream reservoirs.

Sluice-box mining and "sniping" also produce a fine sediment load, but since they are small-scale operations, their total effect is slight. They are most widespread during depression years and are difficult to discover and control.

Hard-rock mining, in itself, is a negligible source of sediment, but the dumps and spoil piles of finely ground material may become a serious menace if they are placed so close to a stream that it can cut into the base of the dumps. This has been done in many drainage areas, especially near Grass Valley, at Jackson, Melones Camp, and Woods Creek above Don Pedro Reservoir.

Hydraulic mining is always a major source of sediment production as it puts vast quantities of suspended load into a stream. Although debris storage barriers are now required by law, some sediment, particularly the finer fractions of the stream load, may be carried over the debris dams.

Lumbering. Lumbering is an increasingly important industry in the Basin. It is largely confined to the higher mountain areas, usually above 5,000 feet elevation. Unwise cutting practices have left large areas denuded of protective cover, and these undoubtedly are now producing more sediment than formerly. Skid trails have led to gully formation, and improperly drained access roads built on steep slopes may be quickly eroded.

Fire. Most parts of the Sacramento-San Joaquin Basin have been burned over from once to many times. Several factors bring about acceleration of erosion after burning. The following are among the more important: (1) Loss of protective cover to ease impact of raindrops; (2) increased dehydration of soil caused by removal of shade; (3) loss of retarding action of vegetation and consequent greater velocity of surface runoff; (4) removal of organic soil binders; (5) easier formation of linear gullies through removal of path obstacles; and (6) development of second-growth vegetation that is often inferior for delaying erosion and that hampers regrowth of original species. Recently burned areas are prolific sources of sediment from sheet and gully erosion.

Road construction and other works. Much sediment comes from erosion along roadways. This is particularly true of unpaved county and mountain roads where inadequate drainage provisions have been made. Although roadside erosion was not evaluated separately, it is reflected in the high sediment-production indices mapped in some drainage basins. Another source of new sediment is provided when plots of land are scraped and leveled. This was noticed frequently in new suburban and resort developments. Often no attempt was made to stabilize new fills having steep frontal slopes along drainageways.

PROPOSED RESERVOIRS

General Characteristics

The comprehensive plan of the Corps of Engineers for flood control on the Sacramento-San Joaquin Basin streams includes 25 major reservoirs in addition to various channel improvements, levees, and other works. Construction of 16 of these reservoirs was authorized in the Flood Control Act of 1944 (Public Law 534, 78th Congress). The comprehensive survey report of the Corps of Engineers, dated 1 February 1945, proposed changes in location, capacity, and method of operation of certain of the authorized reservoirs, and includes "new projects which are considered essential to give the degree of protection from floods ultimately considered desirable in the basin." Of the 25 reservoirs recommended in this comprehensive plan, 8 would have multiple uses for flood control, irrigation storage, and power; 11 would be used for flood control and irrigation; and 6 would be used solely for flood control. The location of the reservoirs is shown in Figure 1. The pertinent physical characteristics of the reservoirs authorized for construction and proposed for

authorization are shown in Table 1. The tentative plans for operation of these reservoirs are described in the comprehensive survey report of 1 February 1945.

METHODS OF INVESTIGATIONS

General Principles

Rates of sedimentation to be expected in the proposed reservoirs could be estimated (1) by sampling the sediment load transported by streams over an extended period, or (2) by surveys of the sediment accumulated over a period of years in existing reservoirs. Both methods require a number of distinct steps in collection of field data and in their analysis and interpretation.

The second method is more economical in cost and in the time required to arrive at reliable estimates. It was therefore the method adopted in this investigation. In principle it involves the interpolation from observed rates of sediment production from drainage areas controlled by surveyed existing reservoirs to drainage areas above proposed reservoirs. From these interpolated rates of sediment production the rates of sedimentation in the proposed reservoirs and effects of sediment on their life and future operation may be estimated.

A study of the locations, operating features, and the topography and geology of the drainage areas above the reservoirs included in the comprehensive plan of the Corps of Engineers led to their segregation into certain groups that might be expected to have comparable rates of sediment inflow. This grouping was as follows:

A. <u>Southern Sierra foothill drainage areas.</u> *1. Burns. *2. Bear. *3. Owens. *4. Mariposa. *5. Farmington. *6. Big Dry.

B. <u>Southern Sierra high mountain drainage areas.</u> *1. Isabella. *2. Pine Flat. *3. New Don Pedro. *4. New Melones. *5. Terminus.

C. <u>Southern Sierra Intermediate drainage areas.</u> *1. Success. 2. Hidden. 3. Buchanan. *4. Hogan. 5. Nashville.

D. <u>Northern Sierra high mountain drainage areas.</u> *1. Folsom. 2. Bullards Bar. 3. Bidwell Bar. 4. Big Bend.

E. <u>Northern Sierra intermediate drainage areas.</u> 1. Garden Bar.

F. <u>Upper Sacramento Valley drainage areas.</u> *1. Iron Canyon.

G. <u>Northern Coast Range drainage areas.</u> *1. Black Butte. 2. Indian Valley. 3. Monticello.

*Reservoirs authorized for construction.

TABLE 1.--Descriptive Data - Authorized and Proposed Dams and Reservoirs

Reservoir (Name)	Topographic position (a)	Stream (Name)	Drainage area (b) (Sq.mi.)	Ultimate proposed storage: Active (Ac.-ft.)	Inactive (Ac.-ft.)	Total (Ac.-ft.)	Reservoir elevations (U.S.G.S. datum): Normal pool (d) (Ft.)	Min. pool (Ft.)	Spill-way crest (Ft.)	Reservoir area at normal pool elev. (Ac.)	Primary use (e)
Sacramento Basin Streams											
*Black Butte	F.H.	Stony Creek	712	145,000	15,000	160,000	474	418	460	4,600	F.C. & I.
Indian	F.H.	N.Fk. Cache Creek	120	246,000	4,000	250,000	1,465	1,325	1,465	3,500	F.C. & I.
Monticello	F.H.	Putah Creek	604	2,170,000	30,000	2,200,000	467	280	454	22,300	F.C. & I.
*Iron Canyon	V.	Sacramento River	2,600 (f)	453,000	41,000	494,000	378.5	316	330	16,200	F.C., P. & I.
Big Bend	M.	N.Fk. Feather River	1,445 (g)	906,000	94,000	1,000,000	1,334	920	1,284	3,800	F.C., P. & I.
Bidwell Bar	M.	Md.Fk. Feather River	1,338	1,060,000	140,000	1,200,000	980	650	930	5,800	F.C., P. & I.
Bullards Bar	M.	Yuba River	477	591,000	84,000	675,000	1,900	1,645	1,850	4,200	F.C., P. & I.
Garden Bar	F.H.	Bear River	257	195,000	5,000	200,000	590	373	560	1,900	F.C. & I.
*Folsom	F.H.	American River	1,875	885,000	115,000	1,000,000	466	338	416	11,400	F.C., P. & I.
San Joaquin River and Tributaries											
Nashville	M.	Cosumnes River	435	530,000	20,000	550,000	1,087	869	1,059	4,800	F.C., P. & I.
*Hogan	F.H.	Calaveras River	363	320,000	5,000	325,000	711	566	711	4,500	F.C. & I.
*Farmington	V.	Littlejohn Creek	212	28,000	6,000	34,000	152	139.5	152	3,400	F.C.
*New Melones	M.	Stanislaus River	900	996,000	104,000	1,100,000	960	730	910	7,300	F.C., P. & I.
*New Don Pedro	M.	Tuolumne River	1,080 (h)			1,000,000 (o)					F.C., P. & I.
*Burns	F.H.	Burns Creek	74	2,400	2,200	4,600	296.5	291	296.5	600	F.C.
*Bear	F.H.	Bear Creek	72	6,300	1,400	7,700	413.5	378.5	413.5	300	F.C.
*Owens	F.H.	Owens Creek	26	3,100	500	3,600	408	378	408	200	F.C.
*Mariposa	F.H.	Mariposa Creek	108	21,500	2,000	23,500	452.5	394	452.5	700	F.C.
Buchanan	F.H.	Chowchilla River	234	60,000	10,000	70,000	538	466	518	1,200	F.C. & I.
Hidden	F.H.	Fresno River	236	80,000	10,000	90,000	534	453.5	534	1,600	F.C. & I.
*Big Dry	V.	Big Dry Creek	86 (i)	15,500	500	16,000	425	405	425	1,500	F.C.
Tulare-Buena Vista Lake Area											
*Pine Flat	M.	Kings River	1,542	970,000	30,000	1,000,000	951	660	924	5,900	F.C. & I.
*Terminus	F.H.	Kaweah River	560	140,000	5,000	145,000	690	553.5	690	2,100	F.C. & I.
*Success	F.H.	Tule	417	105,000	10,000	115,000	659	592.5	659	3,300	F.C. & I.
*Isabella	M.	Kern River	2,080	500,000	50,000	550,000	2,605	2,532.5	2,590	11,100	F.C. & I.

* Authorized reservoirs
(a) F.H. = Foothill; M = Mountain; V = Valley
(b) As reported by U.S.Engineers in Comprehensive Flood Control Survey Report on Sacramento-San Joaquin Basin Streams, California. 1 February 1945.
(c) Total storage and other details not yet finally determined
(d) Normal pool refers to maximum controlled level. If the reservoir is gated this refers to elevation at top of gates; otherwise it is the elevation of the permanent spillway sill.
(e) F.C. = Flood Control; I = Irrigation; P = Power
(f) Excluding 6,665 square miles of drainage area above Shasta Dam
(g) Excluding 615 square miles of drainage area above Lake Almanor
(h) Excluding 454 square miles of drainage area above Hetch-Hetchy Dam
(i) Includes drainage area of Dog Creek above proposed diversion into Big Dry Creek

From the records of the Division of Water Resources, State of California(6), lists were prepared of all existing reservoirs that might be suitable for survey and that would have drainage-area characteristics similar to those of the reservoirs in each of the above groups. A field reconnaissance was made to inspect these reservoirs and to select for survey a representative group sufficient in number and characteristics to provide a basis for estimating rates of sedimentation for each of the above groups. In some cases it was found that the drainage area of an existing reservoir represents the entire drainage areas of one or more proposed reservoirs. For example, the drainage areas of Pardee, Exchequer, and Don Pedro Reservoirs are comparable in most respects to those of the proposed reservoirs in Group B. In other cases, however, as in Groups A and F, the drainage area above any existing reservoir represents only a fraction of the drainage area above a proposed reservoir. Therefore, it was necessary to make a number of reservoir surveys for these groups and to proportion the rates of sediment production determined from each of them to the comparable sections of drainage areas above the proposed reservoirs. In making estimates for each group, consideration was given to all data obtained, but greater weight was given to data from the reservoirs selected specifically to represent this group.

Twenty surveys of various degrees of detail were made on existing reservoirs. In addition, previous surveys by other agencies on 4 additional reservoirs were recomputed and used in this analysis. The data from these 24 surveys form the primary basis for estimates of rates of sedimentation in the proposed reservoirs.

Sediment deposited in reservoirs having different operating practices may vary widely in average porosity, or specific weight. Therefore, in order to have uniform basis for comparison, it is necessary to estimate the average specific weight of sediment in each reservoir and to convert the measured volume to its equivalent weight, ordinarily expressed in tons. In other words, an acre-foot of sediment measured in one reservoir is not necessarily equivalent to an acre-foot deposited in another reservoir. In order to convert all measurements to a uniform weight basis, samples for volume-weight determinations were collected in most reservoirs surveyed. The extreme range in results showed that an acre-foot of sediment in one reservoir was equal in weight to 1.7 acre-feet of sediment in another reservoir. The sediment in either of these reservoirs, if deposited in certain of the proposed reservoirs, might lie at any point within this range or even within a somewhat greater range.

The sediment deposited in a reservoir does not represent all of the sediment inflow. Some of the finer sediment remains in suspension and passes over the spillway or through the service outlets in the dam. In some flood-detention basins, which have open or gated outlets at or near the original stream-bed level, even part of the coarser bed-load material may pass entirely through the reservoir during flood flows, or may be partially sluiced out by succeeding low-water flows. It is necessary to estimate the proportion of sediment passing the dams of existing reservoirs

in order to estimate the total sediment production from the drainage area during the period of record. For this study, such estimates were made from general considerations, as explained later, from specific data on outflow from Pardee and Bullards Bar Reservoirs, and from comparison of records of sediment accumulation in La Grange and Don Pedro Reservoirs.

The reservoir sedimentation records obtained by the surveys cover periods ranging from 5.6 to 94 years. Some of the records of shorter duration, mainly those of less than 20 years, may not be fully representative of a long-term average because of higher or lower average rainfall and runoff during the period of record, as compared with the long-term average, or because of unusual floods or prolonged droughts. Hydrologic records were studied in order to determine whether adjustment of the measured rates to probable long-term averages was necessary or possible. The results of this study are explained in subsequent paragraphs.

These procedures led to an estimated long-term rate of total sediment production for the drainage area of each reservoir surveyed. This rate is expressed in tons per square mile per year in Table 2.

The next problem involved in the investigation was the application of these rates to the proposed reservoirs. As a basis for determining the comparability of drainage-area characteristics, with reference to sediment production, above the surveyed and proposed reservoirs, reconnaissance conservation surveys were made of some 13,000 square miles. These surveys gave a broad generalized classification of soil, slope, land use, and erosion conditions. They provided a basis for judging the proper adjustments of measured rates that should be made in estimating sediment inflow to the proposed reservoir.

In some drainage areas the effects of former hydraulic and placer mining are reflected in the presence of unusual quantities of bed material in the stream channels. In a few streams unusual quantities of bed load seem to be moving. Certain special studies were made of these conditions by application of formulas for bed-load transportation and by interpretation of data on mining activities. These studies led to further adjustment in estimated rates of sediment production from the drainage areas of certain proposed reservoirs.

From the data as thus adjusted, estimates were made of the expected sediment inflow to each of the proposed reservoirs. The percentage of sediment expected to be trapped in each reservoir was estimated from an empirical trap-efficiency curve and from other considerations, as explained. The average specific weight to be expected was estimated for each proposed reservoir from the volume-weight determinations made in 12 of the existing reservoirs. This permitted conversion of sediment inflow in tons to acre-feet of deposits. In addition, studies were made of the distribution of sediment by elevation in a number of the surveyed reservoirs. From these studies the distribution of sediment to be expected at various levels in each of the proposed reservoirs can be estimated when the levels are finally determined.

Table 2. Rates of Sedimentation in Reservoirs Surveyed in Sacramento-San Joaquin Basins

Name of Reservoir	Drainage basin (a)	Sediment-contributing drainage area (b)	Altitude: Reservoir crest elevation	Altitude: Mean drainage area elevation (c)	Altitude: Approximate highest drainage area elevation	Storage Capacity: Total original or at date of first survey	Storage Capacity: Per square mile of drainage area (d)	Length of sedimentation record: Period	Length of sedimentation record: Years	Class of data (e)	Total sedimentation during period		Loss of capacity to date of survey	Average specific weight (f)	Average annual sedimentation per square mile of drainage area		Trap efficiency (g)	Estimated annual sediment production rate per square mile of drainage area
		Sq.mi.	Ft.	Ft.	Ft.	Ac.-ft.	Ac.-ft.	Period	Years		Ac.-ft.	Tons	Percent	Lbs./cu.ft.	Ac.-ft.	Tons	Percent	Tons
Big Canyon	Sac.	5.5	760	1,500	1,900	200	36	11/34-10/45	11.0	1	4.2	4,116	2.08	45(f)	.07	75	76.0	99
Blodgett	Sac.	3.1	156	200	240	258	83	3/40-10/45	5.6	1	3.7	3,707	1.44	46(f)	.21	214	86.2	248
Bullards Bar	Sac.	479.	1,600	5,030	7,500	31,500	66	10/19-1/39	19.2	3	2,607.	3,974,632	8.28	70	.31	432	83.0	520
Combie	Sac.	129.	1,600	2,940	5,300	8,545	66	6/28-10/35	7.3	2	705.	1,074,843	8.25	70	.75	1,137	83.0	1,370
Copperopolis	S.J.	2.0	973	1,200	1,700	265	132	-/15-8/45	30±	1	2.1	2,516	0.79	55(f)	.03	42	91.0	46
Crane Valley	S.J.	52.7	3,365	5,250	8,500	45,410	833	-/01-6/46	45±	3	382.	515,837	0.84	62	.16	218	96.9	225
Davis	S.J.	7.6	110	130	300	1,421	181	-/17-9/45	28±	1	53.5	73,409	3.76	63(f)	.25	345	92.9	371
Don Pedro	S.J.	996.	610	4,225	10,500	289,000	290	3/23-11/45	22.7	3	4,734.	6,392,604	1.64	62	.21	283	93.5	303
East Park	Sac.	98.9	1,198	2,250	7,000	41,098	405	12/10-2/46	35.2	1	659.	803,624	1.60	56(f)	.19	231	94.1	245
Exchequer	S.J.	1,022.	710	5,230	11,500	289,000	283	9/26-3/46	19.6	2	3,354.	4,529,107	1.16	62(f)	.17	226	93.4	242
Faulke	Sac.	.68	750	800	1,100	130	183	-/51-12/45	94±	1	9.4	11,056	7.23	54(f)	.15	173	92.9	186
Gerber	Sac.	.28	448	500	550	190	613	6/17-12/45	28.5	1	7.8	13,251	4.11	78(f)	.98	1,661	95.4	1,741
Gilmore	S.J.	4.9	225	250	325	579	116	9/17-8/45	28.0	1	18.2	19,820	3.14	50(f)	.13	144	90.0	160
Hume	S.J.	24.1	5,300	6,250	8,000	1,410	58	6/09-6/46	37.0	3	27.2	36,730	1.93	62	.03	41	82.0	50
Kerckhoff-Dam No. 6	S.J.	1,184.	971	7,300	13,000	4,200	4.4	-/20--/39	19±	3	1,868.	2,847,953	-----	70	.08	127	51.1	249
La Grange	S.J.	1,501.	299	4,225	10,500	2,332	1.6	9/95-10/05	10.1	2	1,264.	1,927,094	54.20	70	.08	127	41.9	303
Lyons	S.J.	39.7	4,220	5,700	9,300	5,500	137	6/30-6/46	16.0	3	64.1	97,727	1.17	70	.10	154	91.3	169
Magalia	Sac.	8.1	2,234	2,900	3,600	3,718	453	1/18-1/46	28.0	1	69.5	74,172	1.87	49(f)	.31	327	94.6	346
McCarty	S.J.	.33	1,147	1,200	1,700	96	274	12/37-9/45	7.7	1	.74	725	0.77	45	.29	285	93.4	305
Misselbeck	Sac.	11.8	2,200	3,800	7,000	4,300	358	5/20-12/45	25.5	3	214.	349,569	4.98	75(f)	.71	1,162	94.0	1,236
Pardee	S.J.	383.	568	4,160	10,000	210,000	543	-/29-8/43	14±	2	817.	1,103,244	0.39	62	.15	206	95.0	217
Salt Springs Valley	S.J.	18.4	1,173	1,150	2,500	12,930	637	-/82-7/45	63±	3	233.	253,737	1.80	50	.20	219	95.5	229
Stony Gorge	Sac.	197.	841	2,250	7,000	48,889	246	11/28-3/46	17.3	1	670.	788,000	1.37	54(f)	.20	231	93.1	248
Upper Bear River	S.J.	28.2	5,874	7,500	9,000	6,712	236	9/00-6/46	45.8	3	22.2	33,846	0.33	70	.02	26	93.1	28

(a) Sacramento basin = Sac. San Joaquin basin = S.J.
(b) Effective sediment-contributing area below larger upstream reservoirs; excludes surface area of this reservoir.
(c) The mean elevation of drainage area is taken as that elevation at which 50 percent of the area lies below and 50 percent lies above.
(d) Including surface area of this reservoir, but excluding drainage area above any larger upstream reservoirs.
(e) Class 1 data - excellent; estimated chance of error exceeding ±5 percent is less than 1 in 20. Class 2 data - good; estimated chance of error exceeding ±15 percent is less than 1 in 20. Class 3 data - fair; estimated chance of error exceeding ±30 percent is less than 1 in 20.
(f) Mean of analyses of representative samples.
(g) Interpolated values from curve drawn from points of determined trap efficiency in Pardee, Bullards Bar, and La Grange Reservoirs.

Reservoir Sedimentation Surveys

The reservoir sedimentation surveys were made by methods developed by the Soil Conservation Service(7), but modifications of these methods were made in the interest of economy where such modifications would yield results within the desired limits of accuracy.

In the most accurate surveys a triangulation net for horizontal control over the reservoir area was established by plane table and telescopic alidade. From this control the spillway crest contour was mapped. Ranges for direct measurement of water and sediment depths were laid out and tied into this net. Measurements were taken along these ranges at intervals of 25 to 50 feet. The position of each measurement was established by "cut-in" intersection from a plane-table station at the point of a triangle with the range ends. Water depths were obtained with a 5-pound, conical aluminum sounding weight attached to a marked line that could be read to 0.1 foot. Sediment depths were obtained directly with a "spud."(1) The resulting range data were plotted as cross-section profiles of the sediment surface and original bottom. The cross-sectional areas of each profile were planimetered and these data, together with surface areas at spillway contour between adjacent ranges, were used to compute the sediment volume by the formula:

$$V = \frac{A'}{3}\left(\frac{E_1+E_2}{W_1+W_2}\right) + \frac{A}{3}\left(\frac{E_1}{W_1} + \frac{E_2}{W_2}\right) + \frac{h_3E_3+h_4E_4+h_nE_n\cdots}{130{,}680}$$

Where:
- V equals original capacity or sediment volume, in acre-feet.
- A' equals the quadrilateral area, i.e., the area of the quadrilateral formed by connecting the points of range intersection with crest contour between the two principal or most nearly parallel ranges, in acres.
- A equals the lake area of the segment, in acres.
- E equals the cross-sectional area of original capacity or sediment volume cut by a bounding range, in square feet.
- W equals width (length of bounding range) at crest elevation, in feet.
- h equals the perpendicular distance from the range on a tributary to the junction of the tributary with the main stream, or if this junction is outside the segment, to the point where the thalweg of the tributary intersects the downstream range, in feet.

Surveys made by this method, where sediment identification was uniformly good, have proved by various tests to be in error by less than ±5 percent in more than 95 percent of the tests. These are rated as class 1 surveys (Excellent).

Several modifications of the standard survey method were used where they produced greater economy of time without undue loss of accuracy. On some small reservoirs, enlarged aerial photographs were

used without triangulation control in lieu of shore-line mapping. The crest contour was drawn from field examination and the correct scale of the photograph was established by chaining between identifiable points. Ranges and cut-in stations were located on the photos in the field by reference to identifiable points. These modifications do not increase the probable error in sediment-volume determination more than a fraction of 1 percent, and hence the results are considered to be class 1 data.

For some larger reservoirs, original topographic maps were available and were used as a base for survey. Triangulation control was omitted. Ranges and cut-in points were located with reference to topographic features. In the delta section of the reservoir where direct measurements of sediment thickness were not possible, original bottom profiles were drawn by plotting directly from the original reservoir topography. These surveys are rated as class 2 data (Good), which are considered to be accurate within an error of ±15 percent in 95 percent of the surveys.

In addition to these detailed surveys, reconnaissance surveys were made of a number of reservoirs. The reconnaissance surveys were made without instrumental control for location of sediment measurements. The number of observations per range and the number of ranges were reduced to a minimum. All sediment observations on a range were averaged, and one-half the sum of the average depths on adjacent ranges was multiplied by the distance between ranges to give the sediment volume for each segment. These surveys are rated as class 3 data (Fair), which are considered to be accurate within an error of ±30 percent in 95 percent of the surveys. Comparison of sediment volumes determined by reconnaissance surveys followed by detailed surveys on six reservoirs surveyed during this investigation is as follows:

Table 3. Comparison of Results of Reconnaissance and Detailed Reservoir Surveys

Reservoir	Reconnaissance surveys Sediment volume	Detailed surveys Sediment volume	Deviation from detailed survey
	ac.-ft.	ac.-ft.	percent
Big Canyon	3.8	4.17	-8.9
Blodgett	4.1	3.71	+10.5
Copperopolis	2.32	2.06	+12.6
Davis	39.5	53.47	-26.1
Gilmore	17.5	18.17	-4.2
McCarty	.558	.74	-24.6

Specific Weight and Mechanical Composition of Sediment

To determine the average weight of sediment, numerous representative sediment samples were collected in 12 surveyed reservoirs. For this purpose, a 3-section, hollow, steel-pipe sampling device was used. This consists of a central section containing a butterfly valve that remains open when the sampler descends. On being pulled to the surface, the butterfly closes to make a watertight seal. The lower pipe section joined to the central section is used as a spacer, and the collecting receptacle or nipple is screwed to its base. This nipple is a 6-inch length of threaded 2-inch galvanized iron pipe. The upper section of the sampler is a 3-foot length of pipe with a ring or collar at the top for attaching a rope. The entire coupled sampler is 14 feet in length. To use, a nipple is screwed into place at the bottom and the sampler is lowered rapidly to the bottom of the lake by means of an attached line. The sampler penetrates to a depth ranging from a few inches to 3 or 4 feet. Care is taken to prevent complete penetration so that only lake sediment is retained in the pipe. The sample is hauled up, the nipple is detached and immediately secured by screwing caps on both ends.

Collected samples were taken to a soils laboratory where they were weighed wet, then dried and reweighed. The nipple in which the sample was collected has a measured volume. Therefore, the dry weight of sediment can be computed in terms of pounds per cubic foot of deposits in place.

The same samples used for specific-weight determinations were also used for mechanical analyses. This is done by use of calibrated sieves to segregate sand grades and by hydrometer measurements of silt and clay grades. The results are computed in percent weight of each grade in the entire sample.

Drainage Area Surveys

Reconnaissance surveys were made of all drainage areas above reservoirs surveyed and above the sites of proposed reservoirs authorized for construction. These surveys were a slight modification of the reconnaissance soil conservation surveys made by the Soil Conservation Service for the purpose of land use and soil conservation planning[(15)]. The factors mapped were soil group and texture, soil depth, percent slope and slope class, degree of erosional activity, and land use. The nine soil groups mapped represent combinations of four types of profile characteristics according to compaction depth to hardpan and parent material (granite, basic igneous, sedimentary, etc.). Soil texture was defined in six broad classes (coarse, light, medium, heavy, very heavy, and undifferentiated), and three conditions (gravelly, stony, and rock outcrop). Soil depth to hardpan or bedrock was divided into three groups (0-18 inches, 18-36 inches, 36 inches or more). Average slopes within each mapped unit were estimated within five classes (0-3 percent, 3-10 percent, 10-20 percent, 20-40 percent, and 40 percent or more). The estimated average percent slope was also shown numerically.

Soil erosion was mapped to show, insofar as possible, the current erosional activity rather than the erosion status or the past extent of erosion. Sheet erosion, defined in this survey as soil erosion without the development of gullies that are too deep to cross with tillage implements, was classified as slight, moderate, severe, and very severe. Gullying was indicated by symbols representing "frequent shallow," "occasional deep," and "frequent deep." Geologic erosion found generally at the higher elevation was designated separately.

Present land use was classified as cultivated, woodland, pasture (grassland), brushland, and steep, rocky areas.

From this combination of factors the conservation surveyor estimated for each mapped unit its relative sediment production and assigned one of seven numerical values (+ -deposition, 0-none, 1-very slight, 2-slight, 3-moderate, 4-high, and 5-very high). Other factors that might aid in interpretation of the maps, such as M-mining activities, RB-recent burns, W-logged areas, were also shown.

It was impossible to map all drainage areas in the same intensity. The small drainage areas above surveyed reservoirs were mapped on aerial photographs to a scale of approximately 1 inch equals 0.1 mile. On this scale an experienced conservation surveyor will map up to 10 square miles per day depending on the accessibility of the area. On larger drainage areas, U. S. Geological Survey topographic quadrangles on scales ranging from 1 inch equals 0.5 mile to 1 inch equals 2 miles were used. Where quadrangles were not available, Forest Service planimetric maps and Coast and Geodetic Survey aeronautical charts were used. In the large areas, mapping was done at the rate of 100 square miles or more per day.

The drainage areas of the Kern, Kings, Merced, Kaweah, Tule, Madera, Fresno, Upper San Joaquin, and Middle Sacramento River basins and the Merced foothill area had been previously mapped by the Soil Conservation Service using a somewhat different classification method. Less time was spent in field coverage of these areas, but the more serious erosion areas were inspected and the original mapping was converted to the present classification system.

It should be recognized that classification of erosional activity and assignment of sediment production indices is entirely qualitative. There are no existing experimental data or quantitative measurements in the Sacramento-San Joaquin area on which to base a quantitative appraisal of erosion from particular soil-slope-cover complexes. Erosion on forest lands of 45-percent slope in middle elevations of the Sierras and on grazing lands of 15-percent slope in the foothills may be given the same classification although the annual soil loss in tons may be several hundred percent different. Therefore, a sediment-production index of 2 in one type of country is significant only with respect to other indices in the same type of country. For drainage areas of similar

characteristics, however, comparison of the survey data gives a useful basis for estimating the net sediment production from the contributing drainage area above a proposed reservoir by reference to similar drainage areas above surveyed reservoirs.

In order to facilitate study and use of the survey data, the unit areas classified in each sediment-production index in each drainage basin were planimetered and tabulated. For some of the smaller areas, a complete tabulation was made of unit areas having each combination of factors mapped. Because of the large amount of time and facilities required for compilation of similar data for the large drainage areas and because of the lack of comparable detail in some areas, it was decided not to carry the analyses for all drainage areas to this degree of detail.

Channel Bed-load Studies

In addition to the sediment load derived from sheet wash, gullying, and channeling of minor drainageways, much bed-load material is derived from bank cutting and channel scour in some streams. Some of the streams in the foothills and margins of the Great Valley are loaded with considerable quantities of sand and gravel that are being moved downstream mainly as a function of stream flow. The greater the velocity of flow, the greater is the rate of transportation of bed-load material. Hence, any reservoirs built on streams where significant amounts of this previously eroded material are in transit will have a higher rate of sedimentation than would be indicated by extrapolation of sediment-production rates from reservoirs above which there was no appreciable bed-load material already in transit.

Field studies indicated that Big Dry Creek near Fresno and, to a lesser extent, Cottonwood and Clear Creeks in the northeastern Sacramento Basin were the only streams above the site of a proposed reservoir on which such conditions are pronounced. Einstein[8] has developed a formula for computing the quantity of bed load that may be expected to pass any given point in the channel.

RESULTS OF INVESTIGATION

Reservoir Sedimentation

The results of the reservoir sedimentation surveys are shown in Table 2. Of the 24 surveys, 20 were made during this investigation. The survey data on Pardee Reservoir were obtained from the East Bay Municipal Utilities District of Oakland, California[11], and were recomputed by the same methods used for computation of other survey data. The survey data on Bullards Bar and Combie Reservoirs were obtained from the California Debris Commission and were similarly recomputed. The data on Kerckhoff Reservoir and Big Creek Dam No. 6 were obtained from an unpublished report of the Forest Service[14]. Further notes on the methods of survey and computation of the data for each reservoir are given in Appendix A.

Specific Weight of Sediment

The specific weight of deposited sediment is defined as the dry weight of sediment contained in a unit volume of deposit as measured in place. Specific weight is usually computed in pounds per cubic foot. In order to convert the volumes of sediment measured in the various reservoirs to a comparable basis in terms of weight, determinations were made of the specific weight of various types of sediment in 12 of the 24 reservoirs surveyed. A total of 68 samples were collected and analyzed for specific weight and mechanical composition.

In reservoirs where samples were obtained, the specific weight of each sample, or an average of several samples, was applied to that part of the sediment that had similar physical characteristics and had been deposited at similar depths. From the prorated values the total tonnage of sediment in each reservoir was computed. The relation of total weight to total volume determined the mean specific weight for each reservoir. For reservoirs which had not been sampled and for all the proposed reservoirs, average values were obtained by analysis of the survey data. The sample data were first arranged in groups and averaged as shown in Table 4.

Table 4. Specific Weight of Sediment in Reservoirs

Group and Condition	Number of Samples	Range in Values	Mean Value
		lbs./cu.ft.	lbs./cu.ft.
1. Silt and clay 75-100%:			
a. Never exposed to air drying	40	28-68	45
b. Exposed once or more to air drying - - - - - - - - - - - -	20	40-80	66
2. Silt and clay 50-75%:			
a. Exposed once or more to air drying - - - - - - - - - - - -	8	52-90	65
3. Silt and clay 0% - - - - - - - -	1	---	79

From these data and from the data on observed distribution of sediments in the surveyed reservoirs, it was concluded that the sediment that constitutes the deltas in each reservoir usually ranges from material containing slightly more than 50 percent silt and clay at the delta front to nearly pure sand and gravel near the upper limit of the delta. Most of each delta except the frontal slope is exposed, if not annually, at least once every few years. The specific weight is therefore estimated to range from approximately 50 to 80 pounds through the delta sections of the reservoirs. The greater bulk of the deposits, however, is nearer the lower end or delta front. Therefore, the mean value of specific weight should be somewhat closer to the 65-pound mean for exposed, air-dried sediment than to the 80-pound value for loose sand. A value of 70 pounds per cubic foot has been adopted in this

investigation as a reasonable average for delta deposits in the reservoirs surveyed. A value of 45 pounds per cubic foot was used as an average for bottom-set beds below the delta when they contain more than 50 percent silt and clay and are seldom if ever exposed to air drying.

The distribution curve for Exchequer Reservoir (see Figure 2) indicates that approximately 80 percent of the reservoir deposits is in the delta. Field measurements show that much of the sediment in the delta is interbedded fine sand and silt and clay. An estimated 10 percent of the deposits in the upper end of the reservoir is nearly pure sand and gravel. An average specific weight of 62 pounds per cubic foot was used for deposits in this reservoir. This value was obtained by taking 20 percent of the deposits at 47 pounds per cubic foot, the mean value of samples taken below the delta front; 70 percent of the deposits at 65 pounds per cubic foot, representing a gradation from about 50 pounds at the toe of the delta to 80 pounds at the upper limit of the silt and clay lenses; and 10 percent of the deposits at 80 pounds. This average value of 62 pounds per cubic foot has been used for all large mountain reservoirs that have a high trap efficiency.

Special conditions may produce a higher or lower specific weight. Hydraulic-mining debris is somewhat coarser and heavier than average. Furthermore, the smaller the capacity/drainage area ratio the greater is the percentage of fine material passing the dam, other factors being equal. Hence, sedimentation of reservoirs with lower capacity/drainage area ratios tends to have a higher average specific weight. In view of these considerations, the specific weight of sediment in Bullards Bar and Combie Reservoirs was estimated to be 70 pounds per cubic foot. Recent deposits in new reservoirs are lighter in weight owing to lack of compaction. Sediment is also lighter when sand is not present or occurs only in small quantity.

TRAP EFFICIENCY OF RESERVOIRS

The trap efficiency of a reservoir is the percentage of incoming sediment trapped. Few if any reservoirs trap 100 percent of the incoming sediment. If any of the inflowing water passes the dam through outlet works or over the spillway, it is safe to conclude that it will contain some very fine sediment although the concentration may be only a few parts per million. Trap efficiency is a function primarily of the ratio of storage capacity to inflow. To lesser degrees it is also a function of sediment characteristics such as texture, density currents, shape of the reservoir, method of reservoir operation, and of other factors. For any given region of similar runoff characteristics, however, the trap efficiency may be related to the reservoir storage capacity per square mile of drainage area, and empirical curves may be plotted to express this relationship(3).

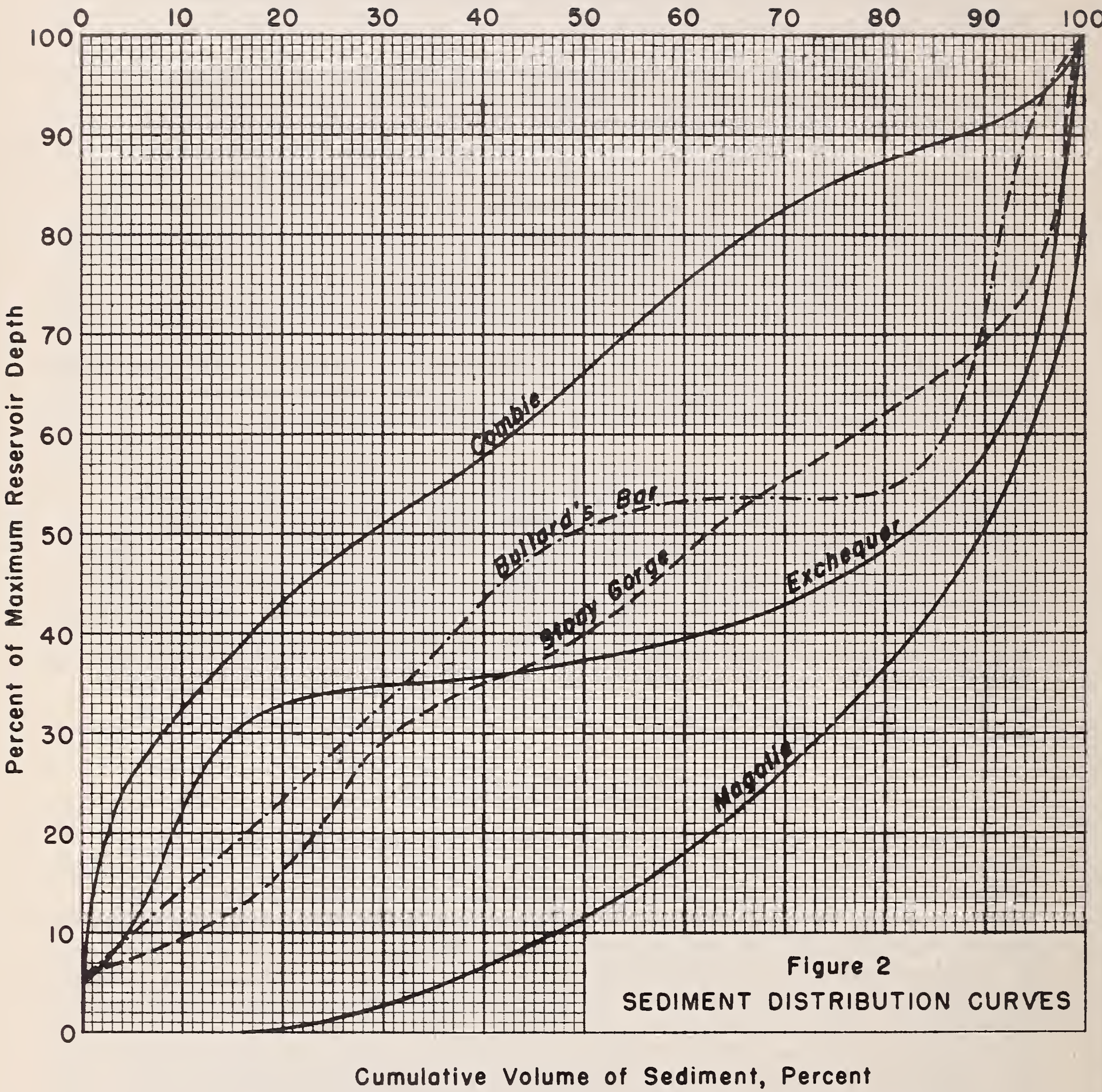

Figure 2
SEDIMENT DISTRIBUTION CURVES

Soil Conservation Service, Washington, D. C., 1947

A trap-efficiency curve must begin at a zero-zero point, for with zero storage there is zero trap efficiency. With increasing storage per square mile of drainage area, the trap efficiency increases and approaches 100 percent asymptotically. Theoretically 100 percent would be reached at the point at which a reservoir would be large enough to hold all inflow at all times with no releases being made for any purpose. Such a condition seldom, if ever, exists because of physical impossibility or economic impracticability.

Having determined the theoretical form of the curve relating trap efficiency in percent to storage capacity per square mile of drainage area, it is possible to plot a usable empirical curve from as few as three well-distributed values. Three sets of such values could be developed for this region.

Pardee Reservoir on the Mokelumne River has a high capacity/drainage area ratio - 542 acre-feet per square mile of drainage area. During a period of 4 years (1940-1943) the stream flow immediately below the dam was sampled for sediment content. From this record Hall[11] computed that 22.689 tons of sediment had been carried past the dam, mainly through the sluiceways and turbines. During this period the outflow from the reservoir was 3,722,800 acre-feet, which is equivalent to 5,059 million tons of water at 1,359 tons per acre-foot. Thus the average sediment concentration was 4.485 ppm, by weight. The application of this factor, expressed in percent, to the reservoir outflow during the 14-year period covered by the sedimentation surveys leads to an estimated total loss of 57,485 tons, compared with 1,103,244 tons deposited in the reservoir at an estimated specific weight of 47 pounds per cubic foot for bottom-set beds and 70 pounds per cubic foot for delta deposits (as determined for Exchequer Reservoir). The sediment loss was therefore 5.0 percent of the total sediment inflow (deposits plus loss).

At Bullards Bar Reservoir on the North Fork of Yuba River, the California Debris Commission sampled the outflow for sediment content during the periods of spring runoff in 1927 and 1928. The results indicated a sediment loss of 0.0573 tons per acre-foot of outflow. The total outflow from Bullards Bar Reservoir during the period of sedimentation record (1921-1938) was 15,348,000 acre-feet, of which 75 percent occurred during the 6-month period, February through July. It was assumed that practically all of the sediment loss occurred during this period and that the factor 0.0573 tons per acre-foot should be applied to 75 percent of the total outflow or 11,511,000 acre-feet. This indicates a loss of 659,580 tons, compared with deposits during the same period of 3,974,632 tons at an estimated average specific weight of 70 pounds per cubic foot. These values indicate a trap efficiency of 83.4 percent for this reservoir, which had an original capacity of 65.6 acre-feet per square mile of drainage area.

The old La Grange Reservoir on the San Joaquin River had, when built in 1895, a storage capacity of 1.6 acre-feet per square mile of

drainage area(13). Its annual rate of sediment accumulation in the first 10.1 years of its life was equivalent to 127 tons per square mile of drainage area. Don Pedro Reservoir, built in 1923 a short distance above La Grange, had a capacity/drainage area ratio of 290 acre-feet per square mile of contributing drainage area and a sediment-accumulation rate of 303 tons per square mile per year, after correction for an estimated trap efficiency of 93.5 percent. There are no known factors that would indicate a difference in the average rate of sediment production from the Tuolumne River drainage basin during the two periods 1895-1905 (La Grange) and 1923-1946 (Don Pedro). Therefore, the relation between 127 tons and 303 tons may be interpreted to indicate a trap efficiency of 41.9 percent for La Grange.

From the values derived as indicated in the preceding paragraph, the empirical trap-efficiency curve shown in Figure 3 was plotted. Trap-efficiency factors for all surveyed reservoirs were taken from this curve and applied to measured rates of sediment accumulation to obtain gross rates of sediment production from the drainage areas above these reservoirs. The curve was also used to estimate trap efficiencies to be expected from the proposed reservoirs with certain modifications for several reservoirs to allow for special operating conditions.

Relation of Measured Rates to Probable Long-term Rates of Sediment Production

The volume of sediment in a reservoir reflects the average rate of sediment production from the contributing drainage area and the average trap efficiency of the reservoir during the period of record. The rate of sediment production is controlled by a number of factors. Those that remain generally unchanged are topography, geology, and soil type. The principal variable factors are rainfall and runoff, land use and treatment, incidence of fire, and progress of accelerated erosion. The sediment-trap efficiency decreases with time, but it is apparent from Figure 3 that so long as the capacity/drainage area ratio is greater than 100 acre-feet per square mile, the trap efficiency will change at an exceedingly slow rate.

Consideration of drainage area characteristics and history during the period of sedimentation records does not indicate any measurable trend toward either increased or decreased sediment production. The sediment production is undoubtedly higher than it was under primeval conditions prior to cultivation, lumbering, man-induced fires, and mining. Any acceleration during the past 10 to 30 years from cultivation, lumbering, and fire appears to have been offset, however, by lessened mining activity, so that the net effects of land use and treatment are believed to have remained fairly constant.

It has been found in analyzing sediment-production records from other major drainage basins that climatic variation, possibly cyclical, of some 10 to 20 years' duration has significantly influenced the

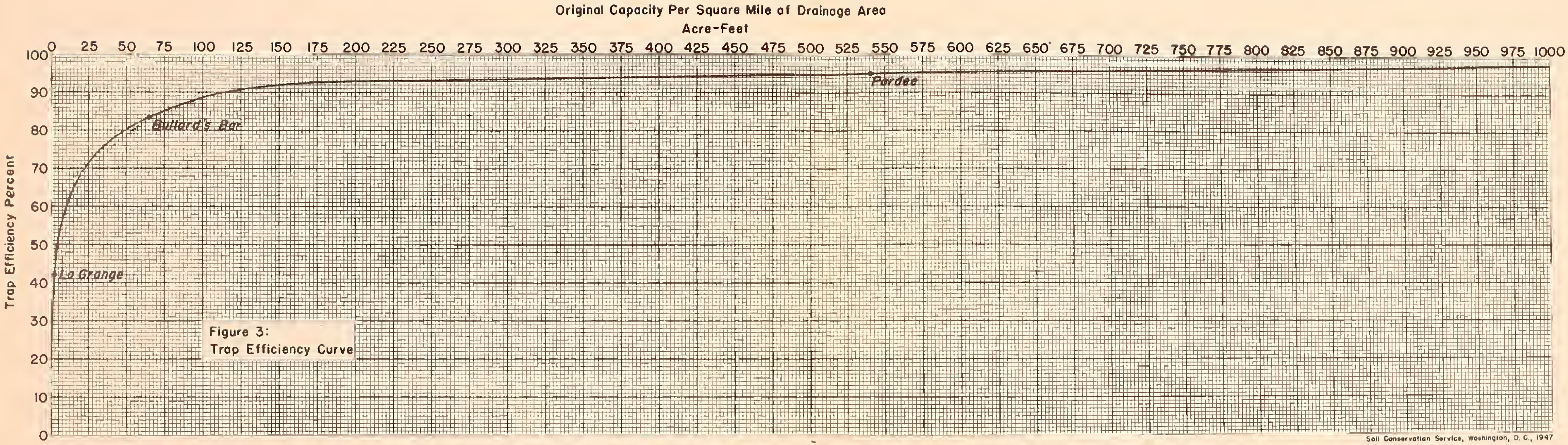

Figure 3:
Trap Efficiency Curve

measured rates of sediment production(4). A study was therefore made of precipitation and runoff records in the Sacramento-San Joaquin Basin to determine whether any trends or periodic variations have been recorded which might indicate that the measured rates of sediment production were either too high or too low. This study showed that flood and drought occurrences during the past 10 to 30 years are not significantly different in terms of frequency or duration from those recorded within the longest available record. As a large part of the sediment deposited in the major reservoirs is relatively coarse material and probably moves for the most part as a direct function of the velocity of stream flow, the frequency and duration of flood flows is probably the most important single factor in controlling the average rate of sediment production. So far as can be determined from available records, the frequency and duration of high flows during the last several decades compares closely with those recorded within the longest periods of discharge measurement. Any slight differences probably would be within the limit of error of sediment determinations and interpolations therefrom, so that no correction for runoff characteristics seems to be warranted.

Distribution of Sediment in Existing Reservoirs

The distribution of sediment at various levels in the proposed multiple-purpose reservoirs is an important consideration in determining their ultimate useful life and in developing a long-range plan of operation. The sediment distribution in any reservoir is the result of several factors, including the capacity/drainage area ratio, the length and shape of the reservoir, the type of sediment, and the method of reservoir operation. In order to obtain data for application to the proposed reservoirs, a study was made of the distribution of sediment in 5 surveyed reservoirs with a range of characteristics. The percentage of total deposits below each range, proceeding from the dam upstream, was computed. It was assumed that the sediment below each range was deposited below the elevation of the lowest point on that range. Because of the high gradients and narrow canyon features of these reservoirs, only a small error resulted from this assumption. This error was equivalent to a wedge of sediment having the range line as its base and lying above the horizontal projection of the contour at the elevation of the lowest point on the range. The height of the lowest point on each range above the original stream-bed level at the dam was computed as the percentage of the total depth from the original stream bed at the dam to the spillway crest. The sediment below each range was then computed as the percentage of the total sediment in the reservoir. From these percentage relationships the curves in Figure 2 were plotted. Table 5 shows the sediment-distribution characteristics of these 5 reservoirs.

Table 5. Sediment Distribution in Surveyed Reservoirs

Name of Reservoir	Capacity/ Drainage Area Ratio	Sediment accumulation to depth Lower 1/4	Lower 1/2	Lower 3/4
	Ac.-ft.	Percent	Percent	Percent
Bullards Bar	66	22	49	91
Combie	66	5	28	60
Stony Gorge	248	27	63	95
Exchequer	283	11	82	97
Magalia	459	68	90	99

It is believed that the factor exercising most control over the sediment distribution is the manner of operation of the reservoir, particularly the prevailing limit of draw-down during the dry season. The second most important factor appears to be the type of sediment.

The wide "benches" on the distribution curves for Exchequer and Bullards Bar Reservoirs reflect the concentration of sediment at the delta front. The position of the delta is probably controlled primarily by the history of the draw-down, particularly the velocity of discharge available for scouring sediment previously deposited farther up the reservoir basin. A similar though lesser flattening of the curve for Stony Gorge Reservoir is apparent. Combie Reservoir shows a much greater concentration of sediment near its upper end. This is believed to be explained by the fact that a period of heavy mining activity immediately preceded the last survey. At the time of the survey there had not been an opportunity for redistribution of this sediment in the lower levels of the reservoir. This is believed to be due to two factors: (1) The reservoir is drawn down to more than half its depth practically every summer, and occasionally has been nearly dry; (2) the sediment is relatively fine-textured, having an average specific weight of only 48.8 pounds per cubic foot, and a silt and clay content ranging from 64 to 98 percent in five samples taken. It is entirely possible, if not probable, that density currents have also been a factor in causing the greater thickness of fine sediment near the dam.

SEDIMENTATION IN PROPOSED RESERVOIRS

Interpretation of Drainage Area Survey Data

The methods by which drainage area survey data were obtained and computed are explained in a previous section. These surveys were made to obtain a basis for comparing the features that affect sediment production from those drainage areas above surveyed reservoirs with similar features of the drainage areas above proposed reservoirs. For example, it was known that the drainage areas of Exchequer, Pardee, and

Don Pedro Reservoirs were most nearly comparable in over-all characteristics to those of Pine Flat, Isabella, and certain other large proposed reservoirs. From the reservoir surveys and adjustments previously explained, the rate of sediment production from the Exchequer drainage area was determined to be 242 tons per square mile, from the Don Pedro drainage area 303 tons per square mile, and from the Pardee drainage area 217 tons per square mile. The question was where the rates for the Pine Flat drainage area, or those above Isabella and other proposed reservoirs would fall with respect to these determined rates.

Inasmuch as no basis existed for determining the quantitative relationship between the individual sediment-production indices for a particular drainage area, or between drainage areas, various trial relationships were assumed and trial-and-error computations of weighted-mean indices were made. For example, in one trial it was assumed that sediment-production Index 2 represented twice as much sediment production per unit area as Index 1, that Index 3 represented five times as much as Index 1, and that Index 4 represented ten times as much as Index 1. Taking the percentages of area in each index within the drainage basin, it was possible to compute a weighted-mean index.

As the drainage areas of East Park and Stony Gorge Reservoirs are as nearly similar as those of any two reservoirs surveyed, a comparison of their weighted-mean indices, as shown in Table 6, was considered significant. The sediment production from the two drainage areas as determined by the surveys is almost identical - 248 tons per square mile annually for Stony Gorge, and 245 tons per square mile annually for East Park.

Table 6. Comparison of Weighted-Mean Sediment-Production Indices for East Park and Stony Gorge Reservoirs

Trial Series	Weighted Mean	
	East Park	Stony Gorge
1-2-5-10	172.5	173.2
1-3-9-27	247.9	246.7
1-2-4-8	170.4	166.5
1-2-3-4	168.3	159.8
1-1.5-5-20	139.0	149.8
1-1.2-10-20	129.4	169.4
1-1.5-10-50	149.5	183.3

From Table 6 it is apparent that the relationship 1-2-5-10 most nearly represents the absolute quantitative relationship. In similar comparisons for several other drainage areas it was found that either this series or the 1-2-4-8 series seemed to represent most closely the

quantitative relationships of sediment-production indices. In the 1-2-5-10 series, the Exchequer drainage area has a weighted-mean value of 152.7, the Pardee drainage area 117.9, the Don Pedro drainage area 160.1, and the Pine Flat drainage area 129.5. On the basis of these values, it is apparent that the sediment-production rate from the Pine Flat drainage area should be intermediate between those of Pardee and Exchequer. A sediment-production rate of 230 tons per square mile annually from the Pine Flat drainage area was thus selected as a logical value between the observed values of 216 tons for Pardee and 242 tons for Exchequer. Similar weighted-mean values were computed for all drainage areas above surveyed and proposed reservoirs. These were used as a guide to estimating rates of sediment production for application to many of the proposed reservoirs, as explained in Appendix B.

Trap Efficiency

Estimates of the trap efficiency of all multiple-purpose reservoirs were based on the curve in Figure 3, the derivation of which is explained in a preceding section. There are no known factors that would indicate differences in trap efficiency between the proposed reservoirs and the larger existing reservoirs. On the other hand, the six reservoirs that will serve solely for flood control, namely, Farmington, Burns, Bear, Owens, Mariposa, and Big Dry, will have outlets at approximately the original stream-bed level. These outlets will normally pass all discharges not exceeding the capacity of downstream channels.

It has been concluded from investigations in other parts of the country that flood-control reservoirs with stream-bed outlets which are normally open will trap only a minor proportion of the sediment coming into them. It has been reasoned that since the outlets will pass practically all discharges not exceeding the downstream channel capacity, virtually all of the sediment load at lower stages should be transported in channel flow completely through the reservoir basin. At higher stages, when water is impounded, the deposits would be spread over that part of the reservoir basin that is inundated. Much of these deposits would take place, however, in the channel near the upper limit of backwater, and this sediment would be subsequently scoured out and carried through the outlets by residual stream flow after all impounded water had passed out of the basin. The percentage of finer silts and clays deposited would be proportional to the length of time available for settlement during the impounding stage. In many drainage basins, silt and clay constitute a major part of the sediment loads of streams. As there would be considerable current through the reservoir area, even at most stages of impoundment, much of the fine material might be expected to remain in suspension and additional amounts would be scoured from the lower reaches of the channel in the reservoir basin after impoundment ceased. Actually, very little quantitative data have been obtained on the trap efficiency of such flood-detention reservoirs, but this line of reasoning has led to the belief that sedimentation would be relatively unimportant.

Table 7. Estimated Rates of Sedimentation in Authorized and Proposed Reservoirs

Name of reservoir	Sediment-contributing drainage area (b)	Altitude: Normal pool elevation	Altitude: Mean drainage area elevation	Altitude: Approximate highest elevation	Capacity per square mile of drainage area (b)	Average annual sediment inflow per square mile (estimated)	Trap efficiency (estimated)	Specific weight (estimated)	Average annual sediment deposit per square mile of drainage area (estimated)		Loss of original capacity (estimated): 50 yrs.		100 yrs	250 yrs.	Time required to deplete 50 percent of capacity (estimated)(h)
	Sq.mi.	Ft.	Ft.	Ft.	Ac.-ft.	Tons	Percent	Lbs./cu.ft.	Tons	Ac.-ft.	Ac.-ft.	Percent	Percent	Percent	Yrs.
Sacramento Basin															
*Black Butte	411	474	1,890	7,000	389	318(d)	94.1	62	299(d)	.22(d)	4,550	2.8	5.7	14.2	900
Indian Valley	120	1,465	2,200	5,000	2,083	247	99.5	55	246	.21	1,250	0.5	1.0	2.5	5,000
Monticello	604	467	1,800	4,000	3,642	250	99.8	55	250	.21	6,300	0.3	0.6	1.4	8,700
*Iron Canyon	2,560	379	1,704	7,000	193	375(e)	93.0	62	349(e)	.26(e)	33,100	6.7	13.4	33.5	400
Big Bend	1,342	1,334	5,000	7,000	745	260	96.1	62	250	.19	12,400	1.2	2.5	6.2	2,000
Bidwell Bar	1,307	980	5,200	7,000	918	260	97.1	62	252	.19	12,200	1.0	2.0	5.1	2,500
Bullards Bar	477	1,900	5,030	7,500	1,415	520	99.0	62	515	.38	9,100	1.3	2.7	6.7	1,900
Garden Bar	127	590	1,500	3,000	1,575	680)(f)	99.0	62	673)(f)	.50)(f)	3,150	1.6	3.3	11.0	1,000
						750)			742)	.55)					
						1,100)			1,089)	.81)					
*Folsom	1,517	466	4,500	9,000	659	540	95.7	62	517	.38	29,050	2.9	5.8	14.5	900
San Joaquin River and Tributaries															
Nashville	435	1,087	3,500	7,500	1,264	217	99.0	62	215	.16	3,450	0.6	1.3	3.1	4,000
*Hogan	363	711	2,000	5,000	895	230	97.0	62	223	.17	3,000	0.9	1.8	4.6	2,700
*Farmington	192	152	500	2,200	177	235	85.0	85	200	.11	1,050	3.1	6.2	15.4	800
*New Melones	746	960	5,770	10,000	1,475	225	99.0	62	223	.17	6,150	0.6	1.1	2.8	4,500
*New Don Pedro (a)	997	-----	4,225	10,500	1,003	303	98.0	62	297	.22	10,950	1.1	2.2	5.5	2,300
*Burns	74	297	1,700	3,100	62	350	75.0	85	262	.14	520	11.3	22.6	56.5	200
*Bear	72	414	2,300	4,200	107	350	75.0	85	262	.14	510	6.6	13.2	33.1	400
*Owens	26	408	1,650	2,870	138	350	75.0	85	262	.14	180	5.0	10.0	25.0	500
*Mariposa	108	453	2,300	4,200	218	375	75.0	85	281	.15	820	3.5	7.0	17.4	700
Buchanan	234	538	1,800	6,000	299	325	93.6	62	304	.23	2,650	3.8	7.6	18.9	700
Hidden	236	534	2,000	8,000	381	325	94.0	62	306	.23	2,650	2.9	5.9	14.7	800
*Big Dry	86	425	800	3,500	186	550	90.0	85	495	.27	1,150	7.2	14.4	35.9	300
**Friant	1,346(c)	555	7,300	13,000	386	262	94.0	62	246	.18	12,250	2.2	4.5	11.1	1,100
Tulare-Buena Vista Lake Area															
*Pine Flat	1,514	951	8,100	13,000	661	230	95.8	62	220	.16	12,350	1.2	2.5	6.2	2,000
*Terminus	559	690	5,500	11,000	259	400	93.3	62	373	.28	7,700	5.3	10.6	26.6	500
*Success	417	659	3,690	10,000	276	375	93.4	62	350	.26	5,400	4.7	9.4	23.5	500
*Isabella	2,080	2,605	7,070	13,000	264	275	93.3	62	257	.19	19,800	3.6	7.2	18.0	700

* Authorized units of Corps of Engineers' comprehensive plan.
** U. S. Bureau of Reclamation reservoir, completed 1940.
(a) Estimates based on assumed capacity of 1,000,000 acre-feet.
(b) Differs from drainage area shown in Table 1 taken from Corps of Engineers' report, owing to exclusion of drainage areas above upstream reservoirs that are effective sediment traps and surface area of proposed reservoirs at normal pool level.
(c) Effective sediment-producing area, adjusted for upstream reservoirs.
(d) Allowing for sediment passing Stony Gorge Dam.
(e) Allowing for sediment passing Shasta Dam.
(f) Top figure is for first 50 years (after 1955), second figure for second 50 years, and third figure for remaining years. Computed on basis of drainage area below Combie Reservoir.
(g) Computed from average annual sediment deposit per square mile in tons, specific weight and drainage area as given in this table. Rounded off to the closest 50 acre-feet above 1,000 acre-feet and to the closest 10 acre-feet below 1,000 acre-feet.
(h) To nearest 100 years.

Consideration of the characteristics of the six flood-control projects in the San Joaquin Basin leads, however, to somewhat different conclusions. A large part of the sediment brought into these basins will be relatively coarse material which will be deposited immediately at the head of backwater during any stage of impoundment. On the receding stage of impoundment, stream-flow velocities will be insufficient to entrain and transport much of this material to the dam, as these velocities will be considerably less than those that brought the sediment into the reservoir. Not only will the total discharge be less than at the higher stages of the flood when impoundment is occurring, but the gradient of the channel through the reservoir basin is less than that in the reaches above; hence, the transporting capacity for coarse material will be less.

Furthermore, the reservoir outlets, as tentatively designed, would have very low grades. The outlet channels discharge into stilling basins. The tentative outlets are so designed that they would not allow passage of much coarse sediment except under head created by impoundment. During impoundment coarse sediment will not be carried through the outlets, so that only the sediment previously accumulated in the conduits or immediately upstream will be removed. After considering the characteristics of the outlets as now designed, the nature of the sediment load, the topographic characteristics of the reservoir basins, and the proposed method of operation, it is the opinion of the writers that only a minor part of the coarse sediment will find its way through the flood-control reservoirs. Most of the material that is discharged will be the fine fraction, or true suspended load. It is believed that the trap efficiency of all the reservoirs will be greater than 50 percent. The trap efficiency may be as high as 85 percent for Farmington, 75 percent for Burns, Bear, Owens, and Mariposa, and 90 percent for Big Dry. Even if a trap efficiency of 50 percent were used in Table 7 , the resulting loss in capacity would affect the economic feasibility of the projects.

Specific Weight

It is estimated that sediment in most of the proposed large multiple-purpose reservoirs will have an average specific weight of 62 pounds per cubic foot. This is based on sample analyses and on study of sediment distribution in Exchequer Reservoir as explained in a previous section. A lower specific weight was estimated for the proposed Indian Valley and Monticello Reservoirs based on the East Park-Stony Gorge data because of the expected smaller proportion of coarse material and the smaller proportion of sediment exposed to air drying.

A specific weight of 85 pounds per cubic foot was estimated for all of the flood-control basins in view of the higher proportion of coarse material and the exposure to drying of all finer sediment during most of each year.

Distribution of Sediment in Proposed Reservoirs

Because most of the proposed multiple-purpose reservoirs will be as large as or larger than Exchequer, this reservoir is believed to be the most representative sample for predicting sediment distribution. Furthermore, the drainage area of Exchequer extends from the lower foothills to the crest of the Sierra Nevada in the same way as drainage areas of Isabella, Pine Flat, Folsom, New Don Pedro, New Melones, and to a lesser extent Nashville, Hogan, Buchanan, Hidden, Success, and Terminus. Thus the curve of distribution for Exchequer in Figure 2 may be used as a general guide in estimating volume of sediment to be expected to deposit at any given pool level. Studies of the probable operation characteristics of Terminus, Success, and Isabella indicate, however, that these reservoirs may be kept empty for months during long dry periods such as that of 1931-1936. During such periods inflow will pass through the reservoir area without significant ponding. Therefore, a larger proportion of the total sediment will tend to be concentrated in the lower levels of these reservoirs than in Exchequer, which is not subject to such extreme draw-down. Allowance should be made for this condition, which is not reflected in the distribution curve of any of the reservoirs surveyed.

It is noteworthy that the distribution curve is not strictly dependent on water stages. A plot of water stages in Exchequer Reservoir against percentage of number of days during which the stage remained within 10-foot depth intervals showed no apparent correlation with position and shape of the delta. This indicates that the effects of draw-down cannot be applied directly in predicting the quantity of sediment that will deposit in any given depth. In general, the Exchequer study showed that with this type of reservoir operation 20 percent of the sediment may be expected to lodge in the lower one-third of the depth, 74 percent in the middle third, and the remaining 6 percent in the upper third. Considerable variation in quantities may be expected in the upper two-thirds of the depth, however, owing to differences in shape and size of the upper delta area, slope of stream bed, and operational characteristics of the reservoir.

Factors Considered in Estimating the Long-term Rates of Sediment Accumulation

Mining Activity. The rates of sediment production determined from surveyed reservoirs include the effects of any mining activity during the period of record. With the exception of Bullards Bar and Combie Reservoirs, no significant effects are reflected in the sedimentation rates. The slightly higher rate for Don Pedro as compared with Exchequer and Pardee may reflect addition of tailings known to have entered the stream from lode-mining operations. On the other hand, the greater possible error in survey results from Don Pedro (class 3 data) may explain the difference in rate. Extensive "sniping" in the Magalia drainage area may be partly responsible for a higher measured rate than was expected for this type of reservoir. On the other hand, dredging operation may

tend to reduce the sediment-production rate, particularly at over-bank stages, through creation of numerous cross-stream barriers and settling basins between gravel dumps. The rate of sediment production from Gilmore Reservoir, which is only 43 percent of that from Davis Reservoir, may reflect the trapping effect of dredging operations, since the drainage area surveys indicate soil, slope, vegetal cover, and similar erosion conditions.

Extrapolation of the measured rates to the proposed reservoirs assumes that mining of no greater extent than has occurred generally during the past 20 to 30 years will occur after the reservoirs are completed. It is obvious that rates of sedimentation may be increased in proportion to the amount of debris made accessible to stream flow from hydraulic or placer mining and mill tailings. The average annual rate for Combie Reservoir for a 2-year mining period (1934-1935) is estimated to have been 1.78 acre-feet per square mile. The rate for the first 3 years of reservoir life (1928-1931) prior to an extensive hydraulic-mining operation was only 0.37 acre-foot per square mile.

Under State and Federal laws, permits must be secured from the California Debris Commission for hydraulic-mining operations and are contingent upon proper storage of mining debris. Storage in several reservoirs can now be purchased for this purpose. It is not difficult to determine with reasonable accuracy the quantity of sediment produced by hydraulic operations. Therefore, any additions to the predicted rates because of new hydraulic operations could be readily made. At present, systematic data are not maintained on dredging, sniping, or dumping of tailing. Fragmentary information indicates that these mining activities have not had nearly so profound an effect on sediment loads of streams as has hydraulicking. Nevertheless they might conceivably double or triple the average annual rates from drainage areas during years in which they are carried on. Provision should be made to systematically measure quantities of sediment derived from future mining of these types, and appropriate increases should be made in the estimates contained in this report.

Logging, Fire, Grazing, Cultivation, and Roads. The measured rates of sediment production represent the average effects of cultural activities on erosion in the drainage areas during the past several decades. There is no evidence that the aggregate effects in the drainage areas of any of the proposed reservoirs is decidedly greater or less than in the drainage areas of the surveyed reservoirs. It should be recognized, however, that there may be trends toward greater cultural and commercial use because increasing pressure on the land resources is to be expected with increasing population.

This trend, if not offset by other factors, would tend to increase rates of sediment production over those of the last few decades. More extensive logging operations, more intensive grazing, greater recreational use of forest areas, accelerated construction of roads, and conversion of grassland to cultivation, all of which are effects of increased population

pressure, would tend to accelerate sediment production. Federal, State, and local agencies are attempting to offset this tendency and to reduce sediment production through their conservation programs.

If these programs and agencies are adequately supported there is no reason to expect increases in sediment production as a result of land use and management. Failure to support these programs, however, might result in significant increases. For example, sediment production from the poorly conserved Gerber drainage area has averaged 1,741 tons per square mile annually, as compared with rates of less than 100 tons per square mile annually from the best protected drainage areas and average rates of approximately 250 tons per square mile elsewhere. The effects of use, management, and condition of drainage areas above the proposed reservoirs should be evaluated every 5 to 10 years to determine whether adjustments should be made in the predicted rates of sediment accumulation.

Climatic Change. There is no generally accepted evidence that would indicate the probability of a significant change in climatic conditions during the next 50 years or more as compared with the past 10 to 30 years. The major floods that have occurred during the life of the existing reservoirs that have been studied are integrated into their record of sediment accumulation. Recurrence of similar events with comparable frequency is to be expected.

Adjustments for Future Upstream Reservoirs. Any reservoirs constructed upstream from the proposed reservoirs subsequent to the date of their construction will reduce the effective sediment-contributing area of such reservoirs. Estimates of sedimentation in any such additional reservoirs could be made from the results of this investigation. The predicted rates of sedimentation in the proposed reservoirs should be reduced by the amount of sediment that will be permanently trapped in any new reservoirs constructed upstream from them.

Conclusions

The estimated rates of sedimentation and other pertinent data on each of the proposed reservoirs included in the comprehensive plan are presented in Table 7. Notes on estimates for individual reservoirs and their drainage areas are given in Appendix B. From the analyses of data presented in this report, the rate of sediment accumulation in acre-feet per square mile annually has been estimated for each of the proposed reservoirs. Based on these estimates, the total storage loss at the end of 50 years, 100 years, and 250 years, as well as the number of years required to deplete 50 percent of the capacity of each reservoir, has been computed.

These data clearly show that the rates of sedimentation in the proposed reservoirs will be low. With the exception of the Burns Reservoir, not one of the proposed reservoirs is expected to lose as much as 10 percent of its capacity in the first 50 years after construction. The reservoirs will retain 50 percent or more of their capacity for periods

ranging from a minimum of 200 years to a maximum of several thousand years. It should be understood, however, that these estimates are based on the logic of probabilities. If a storm or series of storms having a probable recurrence expectancy of once in 500 or 1,000 years should occur, or if marked but unforeseen changes in land use, mining, or fire incidence should take place during the first 50 years after construction, then the average rates of sedimentation for the first 50 years may be materially higher than estimated. It seems highly improbable, however, that any event or combination of events could so increase the rates of sedimentation as to materially affect the service functions or the plan of operation of any of the proposed reservoirs during the first 50 years of their life.

On the other hand, it should be recognized that any degree of sedimentation in a reservoir that is unable to impound the entire stream flow causes some damage, and that this damage may be translated into monetary terms. Any loss of flood-control storage by sedimentation means that the reservoir is able to fully control (i.e., without downstream damage) only a somewhat smaller flood. That is, if the flood-control storage provided initially will permit full control of a flood having a statistically probable recurrence interval of once in 100 years, then even a slight capacity loss may reduce protection to full control of a flood having a recurrence interval of once in 99 years. The difference in this protection can be computed and is one measure of the value of sedimentation control.

Likewise, loss of capacity used for irrigation or power storage reduces the flow-regulating effect of the reservoir if that reservoir wastes water annually or at fairly frequent intervals. If the wasted water could have been stored and usefully released from the space lost by sedimentation, the average annual output of firm power or the average acreage of land supplied for irrigation would be larger. This difference can be measured, but such measurements are beyond the scope of the present investigation.

The low rates of storage depletion from sedimentation in the proposed reservoirs, as compared with those in many other parts of the country, are due mainly to two factors: (1) The prevailingly low rates of sediment production from the contributing drainage areas, and (2) the large ratios of capacity to drainage area, which results in small percentages of capacity loss per unit of sediment inflow. So far as can be foreseen, sedimentation need not be considered a determining factor either in the amount of storage to be provided in any of the reservoirs or in developing a plan of operations covering the first 50 years following their construction. The influence of sedimentation should be considered, however, in the design of outlet works for the six reservoirs to be used solely for flood-control purposes.

APPENDIX A

DESCRIPTION OF RESERVOIRS SURVEYED

Detailed descriptions of each surveyed reservoir, its drainage-area characteristics, the method and results of the sedimentation survey, and characteristics of the sediment are given in this Appendix, which should be consulted for detailed explanation of the data summarized in Table 2.

Big Canyon Creek Reservoir. This reservoir is located in sec. 20, T. 9 N., R. 10 E., El Dorado County, on Big Canyon Creek, a tributary of the Cosumnes River. The reservoir is created by an earth-fill dam 57.8 feet high above stream-bed level and 440 feet long. When storage began in November 1934, it had a surface area of 13.8 acres and a capacity of 200 acre-feet as determined by the survey made during this investigation. The reservoir was built to store water for mining purposes. Outlets in the dam consist of two 6-inch and two 4-inch valves opening into a 36-inch galvanized-pipe riser extending upward to within 4 feet of spillway elevation. Water is released to supplement diminishing stream flow in the late spring and throughout the summer until about December 15. Some 8 to 10 feet of water is left in the reservoir to preserve fish life. During the winter months there is usually a small depth of flow over the spillway. One flow of 300 cubic feet per second over the spillway has been reported.

The drainage area, including the reservoir surface, comprises 5.5 square miles as determined from enlarged aerial photographs on which the scales were established by chaining between identifiable points. The drainage area is relatively elongated and rises from elevation 760 at the dam to about 1,900 feet along the northern divide. The area is steep, rough, and broken and has rather deeply incised canyons. The drainage area survey led to estimates that slopes of 5 to 25 percent occur on 12 percent of the area, of 30 to 35 percent on 38 percent, and of 40 to 45 percent or more on 50 percent.

Precipitation averages 25 to 30 inches annually. Snow seldom falls and is unimportant.

The drainage area is underlain mainly by metamorphosed fine-grained sedimentary rocks, mainly slates and phyllites, presumably part of the Calaveras formation. The soils are generally thin (up to 18 inches) with little or no compaction in the subsoil, and the underlying bedrock is largely impervious.

Native vegetation consists of brush-grass and forest-grass types. The rather dense greasebrush-grass stands may be a replacement of the open-forest type found in other parts of the drainage area, as a result of fire. The land is used primarily for grazing. There is no cultivated land in the drainage area, and no evidence of recent or extensive mining activities. Accelerated soil erosion is slight. No gullying or stream-bank erosion of consequence was observed.

The reservoir survey was based on plane-table triangulation and shore-line mapping on a scale of 1 inch equals 100 feet. Nine ranges were used, and water and sediment depths were measured along these at intervals of 13 to 23 feet. The sediment could be readily distinguished from the underlying original bottom in all measurements, and the survey results are of a high order of accuracy.

A total sediment volume of 4.17 acre-feet was deposited during an 11.0-year period as a thin layer over the floor of the reservoir area. Maximum depths of sediment range from 0.6 foot on ranges near the dam to 2.0 feet in the upper end. There is no true delta. The sediment ranges from 98 percent silt and clay (U. S. Bureau of Soils Classification) near the dam to 60 percent silt and clay and 40 percent sand near the head of the lake. The sand content declines fairly regularly down the reservoir basin. Considerable organic matter is present. The weighted mean specific weight of sediment determined from analyses of six samples was 44.66 pounds per cubic foot. The range was from 39.0 to 55.9 pounds per cubic foot.

The rate of sediment production from this drainage area is low compared with other areas of comparable elevation on which data were obtained. This appears to be due mainly to the well-vegetated condition of the area and to the absence of noticeable soil erosion, gullying, stream-bank erosion, or mining activities.

Blodgett Reservoir. This reservoir is located in sec. 28, T. 8 N., R. 7 E., in Sacramento County, on an unnamed small tributary of the Cosumnes River. The reservoir is created by an earth-fill dam 20 feet high above stream-bed level and 950 feet long. When storage began in March 1940, the storage capacity at crest level was 258 acre-feet as determined by this survey. The reservoir's original surface area of 46.9 acres has not been reduced by delta deposits. The reservoir was built for stock water. No gates or outlets were placed in the dam, but provisions were made to withdraw by syphon. There is no record of significant flow over the spillway.

The drainage area, including the reservoir surface, as determined from enlarged aerial photographs of measured scale, is 3.12 square miles. The topography is gently rolling and for the most part is developed on a gravel terrace into which the drainage is weakly incised. The drainage is somewhat imperfect, with shallow disconnected depressions on the uplands. These fill with water during the rainy season and are dried either by evaporation or percolation into the gravels underneath. The range in elevation is from 156 feet to about 240 feet. Slopes are gentle and rarely exceed 15 percent.

Precipitation averages about 18 inches annually. Snow seldom falls in this area.

The soils are thin and generally overlie gravel beds. Gravel lenses are exposed along the stream banks.

Native vegetation consists of grasses on the slopes and uplands, and low bushes in swales and along the channel. Wild oats form the principal cover. The land is used entirely for cattle grazing. Formerly the area now occupied by the reservoir was farmed. Gravel and dirt roads extend the length of the drainage area and access farm roads cross it at two places. Accelerated soil erosion is slight, and no gullies were observed. Stretches of the channel are being scoured and minor bank erosion occurs in places.

The reservoir survey was based on plane-table triangulation and shore-line mapping on a scale of 1 inch equals 100 feet. Eight ranges were established on which water and sediment depths were measured. Sediment depths range from a maximum of 1.9 feet in the channel at the upper end to about 0.5 foot outside the channel. Average depths outside the channel are 0.1 to 0.2 foot. The pre-lake bottom is gravel or sandy silt loam. It is clearly distinguishable from modern lake sediment.

The total sediment volume of 3.7 acre-feet was deposited during 5.6 years. It consists largely of silt and silty clay. A small quantity of fine sand occurs in the channel. No clearly defined delta exists. The weighted mean specific weight as determined from analysis of five samples was 46 pounds per cubic foot. The range of specific weight of individual samples was 40.5 to 52.1 pounds per cubic foot.

The rate of sediment production is considered moderate for this type of lowland reservoir. Channel erosion appears to be the principal source of sediment.

Bullards Bar Reservoir. The Bullards Bar dam is located in sec. 24, T. 18 N., R. 7 E., in Yuba County, on the North Yuba River. The first dam at this location, completed in October 1919, was 30 feet high. In September 1920 it was raised to 37 feet and in 1922 construction was started on the existing high dam. It was completed in January 1924 as a concrete-arch structure to a height of 190 feet above stream-bed level and has a length of 520 feet. The spillway crest is at elevation 1,600 and is 15 feet below the top of dam. It is designed for flow over the center of the dam. Penstocks near the base are used for hydroelectric power generation.

The surface area of the reservoir at its present elevation was reduced by delta deposition from 500 acres to 491 acres in 1939. The original capacity at the present elevation, as determined by the California Debris Commission by planimetering contours of the original map of 1919, extended in 1921, was 31,500 acre-feet.

Bullards Bar Reservoir was constructed primarily for power and storage of mining debris. The Federal Power Commission authorized the sale of sufficient debris storage space in this reservoir to permit 40 million cubic yards of hydraulic mining above the reservoir. Only a small fraction of this mining has been done to date.

The drainage area, including the reservoir area, as determined from U. S. Geological Survey quadrangle maps, is 480 square miles. The elevation ranges from 1,600 to 7,500 feet. The topography is rough and mountainous. The drainage area receives from 65 to 75 inches of precipitation annually, which includes a considerable amount of snowmelt. Slopes are steep and runoff is high.

Much granite is exposed, and approximately an equal amount of metamorphosed rocks such as schists, slates, and phyllites. Lava flows are found in the northern and eastern parts of the drainage area. The soils are immature and vary from thin on the uplands and slopes to thick in the narrow valleys. Channels are gravel filled in places, but more generally are floored with hard bedrock.

Most of the area is heavily forested. Some valleys have been cleared for range land and are now grass-covered. Some mountain areas are barren from effects of forest fires. A few paved roads cross the drainage area, and unpaved ranch, mining, and lumber access roads radiate from the surfaced roads. Erosion along roadways is not severe. Accelerated erosion is, on the average, slight on the uplands. The major source of sediment is from hydraulic mining from gravels adjacent to stream channels.

The reservoir surveys of the California Debris Commission were used for computing sedimentation. Their soundings made along ranges in January 1939 were plotted on profiles of ranges constructed by interpolation from the original contours of the October 1919 map prepared by the Yuba Power & Development Company. The computed sediment volume of 2,607 acre-feet was accumulated during 19.2 years. The sediment consists principally of silty fine sand, sand, and gravel. The maximum thickness was 60 feet on the top of the delta about mid-distance between the dam and the head of the reservoir. A thickness of 45 feet was found about 1,000 feet upstream from the dam. Except for the delta section and the first mile above the dam, the average thickness was about 10 feet. These are channel thicknesses only; outside the channel the sediment is much thinner. No specific weight determinations were made. An assumed value of 70 pounds per cubic foot was based on the average for large delta deposits in other reservoirs. The mining debris caught in Bullards Bar Reservoir is somewhat heavier than the average sediment, hence the entire volume of deposit is computed at this value.

The rate of sediment production for the entire drainage area is relatively high because most of it comes from hydraulic mining. The actual rate from a similar area without hydraulic mining probably would be no more than half as much.

Combie Reservoir. The Combie dam is located in sec. 2, T. 13 N., R. 8 E., between Nevada and Placer counties on the Bear River. The dam is a variable radial-arch, concrete structure, 75 feet high above streambed level and 762 feet long at its crest. The spillway crest has an elevation of 1,600 feet above mean sea level and is 6 feet below the top of the dam. The spillway is an overflow type. Water can be released from

two sluice gates 15 feet below the spillway sill or from two drainage gates 50 feet below the spillway level.

The original surface area of Combie Reservoir was reduced by delta growth from 338 acres to 329 acres in 1935. The original capacity of 8,545 acre-feet when storage began in June 1928, was determined by planimetering contours of a map made by Fred H. Tibbetts in 1928 and revised and extended by the California Debris Commission in 1935.

The reservoir was constructed primarily for irrigation but space was allotted for storage of hydraulic-mining debris. Intensive mining was carried on during two years within the period of sedimentation record but was stopped by court action when mining debris entered diversion canals above Combie Reservoir. Water is diverted both from and into the Bear River above Combie, but this is believed to have little influence on sediment movement.

The drainage area, inclusive of the reservoir area, as determined from U. S. Geological Survey quadrangle sheets, is 130 square miles. The area is rough and mountainous. The range in elevation is from 1,600 to 5,300 feet. Annual precipitation, principally rainfall but including some snow, varies from 40 inches at the dam to 65 inches at the upper divide. Most of the drainage is heavily forested by conifers and oaks but large areas of hydraulic-mining scars are barren.

Granitic rocks are exposed in the upper part of the drainage area. The lower half is underlain by metamorphic rocks. Soils are immature and moderately deep in the valley bottoms but thin and scanty on slopes and uplands. The channel of the Bear River has lag gravels varying in depth from a few inches to 6 feet. Some stretches are on bedrock.

The capacity of the reservoir in June 1928, June 1931, and October 1935 was recomputed from contour surveys made on a scale of 1 inch equals 500 feet by Fred H. Tibbetts (1928) and the California Debris Commission (1931 and 1935). A total sediment volume of 705 acre-feet, accumulated during 7.3 years (1928-1935) at an average annual rate of 96.5 acre-feet was indicated by these computations. Prior to renewed hydraulic mining which began in 1933, the annual accumulation was only 47.5 acre-feet, or approximately half as much. Most of this sediment probably entered the reservoir during the two-year period of hydraulic mining. The sediment consists of clayey silts, silts, sands, and some gravel. The maximum thickness is about 12 feet in the channel section about midway between the dam and the head of the lake. A well-defined delta begins at the head and extends about half the length of the reservoir. An average specific weight of 70 pounds per cubic foot has been assumed from determinations made in the delta areas in other reservoirs of comparable size. This value is believed justified because of the heavier sediment produced by hydraulic mining.

Sediment production comes largely from hydraulic mining and hydraulic scars that are now eroding. Sheet and gully erosion of the upland slopes

appears to be small. Some channel gravels are moved by the largest floods but the quantity added to the reservoir is probably small.

Copperopolis Reservoir. This reservoir is located in sec. 33, T. 2 N., R. 12 E., Calaveras County, on Penney Creek in the Stanislaus River Basin. The dam is an earth and masonry structure 33 feet high above stream-bed level and 660 feet long at spillway crest, which is 973 feet above mean sea level. The spillway is 2 feet below the top of dam and is an overflow type. Sluice gates are located near the base of the dam but they have not been used because seepage is sufficient to keep filled a catchment pool below the dam. The area at spillway level is 30 acres. When storage began in 1915, the original capacity, as determined by this survey, was 265 acre-feet. The lake was dry for a period of several months some 10 to 15 years ago. Ordinarily it is at or near crest during the winter months but drops to about half its spillway depth by the end of the dry summer and fall season. Originally the reservoir was built for mining water supply but it has not been used for that purpose during the past 10 years. It is now used for the domestic water supply of Copperopolis.

The drainage area, including the lake area, is 2.06 square miles, as determined from enlarged aerial photographs on which the scale of 1 inch equals 545 feet was established by measurement between identifiable points. The area has hilly topography with steep slopes but with an appreciable area of gently sloping valley floor. Elevations range from 973 feet to approximately 1,700 feet. Precipitation is nearly all rainfall and amounts to about 20 inches annually. Most of the hill slopes and upland is forested by oak and other deciduous trees. The valley floor is well grassed and supports livestock grazing.

The bedrock is metamorphic slates and serpentine-like rock. Soils are thin on the slopes and upland but moderately thick on the valley floor. They are principally fine sandy loams.

The reservoir survey was based on a range system controlled from a plane-table triangulation net established on a scale of 1 inch equals 100 feet. The shore line was drawn from the aerial photographs of established scale. Four ranges were used and sediment measurements were made approximately 25 feet apart. The measured sediment volume of 2.1 acre-feet was accumulated in 30 years. The sediment is rather evenly distributed over the reservoir with the maximum thickness of about 1.5 feet in the channel near the dam. The specific weight of 55 pounds per cubic foot is the weighted average of 4 samples that ranged from 39.2 to 70.9 pounds per cubic foot. The sediment is more than 75 percent clay; the remainder is silt with a trace of fine sand.

Sediment production is principally from stream-bank erosion and sheet erosion. A few gullies were observed from the toe of hill slopes but much of their debris was deposited on the valley floor. The extremely low rate of sedimentation suggests that even though erosion is slight, most sediment caused by it is deposited before entering the reservoir.

Crane Valley Reservoir. The dam of this reservoir is located in sec. 25, T. 7 S., R. 22 E., Madera County, on the North Fork of San Joaquin River. The dam is a hydraulic-fill earth and rock structure 145 feet high above stream-bed level and 1,880 feet long. The spillway crest elevation is approximately 3,365 feet above mean sea level. The spillway is cut in rock southeast of the dam. A log crib dam is reported to have been built at this site in 1901. In 1905 two lakes were created by separate dams within the present lake area. In 1910 a larger rock-fill dam was constructed in front of the original downstream dam. It created a lake which covered the area of the two earlier lakes. The present dam was started in 1937 over and in front of the 1910 dam. The capacity of the present reservoir at spillway elevation, as determined by engineers of the Pacific Gas and Electric Company from a contour map made in 1937, was 45,410 acre-feet. In view of the direct estimation of the volume of sediment, this figure is used as the approximate original capacity. The reservoir area at spillway crest is 1,164 acres.

Gates are provided in the lower part of the dam for water release. Water level is at or above crest during the winter and spring but falls a few feet below crest in the summer. The reservoir was created for electric power generation and regulation of downstream flow. Some water is used for irrigation.

The drainage area, including the lake area, as determined from U. S. Geological Survey quadrangle sheets (scale 1 inch equals 2 miles), is 54.5 square miles. The area ranges in elevation from 3,365 to 8,500 feet and is rough and mountainous. Many slopes are more than 40 percent. Annual precipitation ranges from 38 to 50 inches and part of it is snow. The upland and slopes are heavily forested by conifers, chiefly pines, whereas the lower part of the area is mixed pine and oak forest, in part pastured by sheep and cattle. Lumbering is at present unimportant but it has been more extensive in the past. Few roads extend into the drainage area and they are chiefly dirt and graveled. Much bare granite and metamorphic rock is exposed and soils developed on them are thin and scanty on the slopes and uplands but locally deep in the valleys. The soils are granitic at higher levels and grade into sandy loams on the lower slopes.

The reservoir survey was a reconnaissance type. Three ranges selected at approximately 2,000-foot intervals from the dam were spudded without horizontal control. Position of observations was estimated by eye. On each range sediment was measured at 4 to 5 places. The computed sediment volume of 382 acre-feet is assumed to represent the accumulation of 45 years. The maximum sediment depth observed was 2.8 feet, but this is not considered to be the absolute maximum. Sediment distribution is not well-defined by a reconnaissance survey but there were indications of a delta in the upper third of the reservoir. The specific weight was assumed to be 62 pounds per cubic foot. The bulk of the sediment appears to be fine sand.

The sediment-production rate from the drainage area is moderate to low. The principal sediment source is considered to be sheet and moderate gully erosion, although stream-bank erosion occurs in the lower reaches of the stream channel.

Davis Reservoir. This reservoir is located in sec. 6, T. 2 N., R. 9 E., San Joaquin County, on Shaw Creek, a tributary of the Calaveras River. The dam is earth-fill and is 12 feet high above stream-bed level and 2,100 feet long. The spillway has a freeboard of 5.5 feet and the spillway crest has an elevation of 115 feet above mean sea level. The surface area at crest is 160 acres. The spillway is a concrete weir 100 feet wide. The original capacity when storage began in 1917, as determined by this survey, was 1,421 acre-feet. The reservoir was built for irrigation and is drawn down through the summer months until it usually covers only about 10 acres by September. From approximately December to June it is usually at or near crest. The dam was washed out in 1927 or 1928, but the owner reported the reservoir was not completely drained and he is of the opinion that little or no sediment was washed away.

The drainage area, including the reservoir area, is 7.87 square miles, as determined from enlarged aerial photographs having a scale of approximately 1 inch equals 500 feet. The area is moderately rolling valley land ranging in elevation from 110 to approximately 300 feet. Annual precipitation is about 19 inches and occurs almost entirely as rain. Slopes are gentle and seldom exceed 10 percent. The land is used exclusively for grazing. Soils are thin and are formed on gravelly alluvial terraces. The cover is grassy or brushy except on some upland areas which are practically bare.

The reservoir survey was based on a plane-table triangulation net on a scale of 1 inch equals 100 feet. The shore line at crest level was drawn from the aerial photographs with field checking. Eight ranges were spudded to measure sediment depths at intervals of approximately 25 feet. The measured volume of 53.5 acre-feet of sediment represented 28 years of accumulation. The maximum sediment depth measured was 4.6 feet in the channel near the dam. The uppermost range had a maximum sediment depth of 0.3 foot and there was no evidence of a delta. The specific weight of 63 pounds per cubic foot is an average of 7 samples which ranged from 42 to 76 pounds per cubic foot. The clay content of the sediment varied from 12 to 52 percent; silt from 45 to 85 percent, and very fine sand 1 to 25 percent.

The sedimentation rate is judged to be moderate and typical for this kind of drainage area. The principal sediment sources are channel and sheet erosion. Some rilling results from heavy rainfall.

Don Pedro Reservoir. The Don Pedro dam is located in sec. 35, T. 2 S., R. 14 E., Tuolumne County, on the Tuolumne River. The dam is a concrete-gravity, curved-arch structure 278 feet high above stream-bed level and 1,040 feet long. The spillway crest is at elevation 605.5 and is 13 feet below the top of the dam. At crest level the reservoir surface area is 2,900 acres. Don Pedro Reservoir was constructed for irrigation and power. Installed power equipment includes two 7,500 KVA and three 5,000 KVA generators. Other controlled outlets permit additional water to be released for irrigation. The draft under full plant operation is 2,300 cubic feet per second. The annual draft for irrigation is approximately 800,000 acre-feet.

When storage began about March 1923, the original capacity, as reported by the owners from planimetric measurement of an original contour map made in 1913 on a scale of 1 inch equals 500 feet, was 289,000 acre-feet. The reservoir is drawn down under heavy usage during the summer and fall. Water level begins to rise in December but does not reach crest until the snowmelt enters after May. In dry years water does not reach the crest level.

The drainage area, including the reservoir surface, as determined from U. S. Geological Survey topographic quadrangles, is 1,001 square miles. The watershed is rugged and mountainous. Elevation ranges from 605 to about 10,500 feet. Annual precipitation which occurs both as rain and snow ranges from 18 inches at the dam to 50 inches on the highest mountain areas. The predominance of steep slopes, many exceeding 40 degrees, is partially offset as an erosion factor by a good forest cover of pines over most of the drainage basin. A few improved roads extend into the drainage area. Lumbering and some mining are actively under way in various places. The higher areas are of granitic rocks; at intermediate elevations are metamorphic slates, schists and phyllites, and some volcanic extrusives; the lower elevations have exposures of meta-sedimentaries. Soils on granite are shallow on the slopes but locally deep in the valleys. Soils on the metamorphic rocks are shallow and immature. Volcanic extrusives are practically devoid of soil.

The reservoir survey was made by reconnaissance methods using the 1913 map as a base. Eleven ranges spaced at regular intervals were spudded at from 3 to 7 locations. The position at points of measurement was estimated by eye. The sediment varies from clayey silt near the dam to medium sand in the upper end. A pronounced delta extends from the upper end to about one-third the length of the reservoir. This delta contains about 60 percent of the total volume of sediment. The total estimated volume of 4,734 acre-feet was accumulated in a period of 22.7 years. The assumed specific weight of 62 pounds per cubic foot is based on samples collected from Exchequer Reservoir which lies a few miles south of Don Pedro and which has the same capacity and similar drainage-area characteristics.

Sediment production is chiefly from sheet erosion, bank erosion, and gullies. Mining also contributes some sediment, but probably a small proportion of the total load. The rate of sedimentation in Don Pedro Reservoir is considered to be slightly above average for reservoirs of comparable size in the Sierra Nevada. Most sediment is believed to be coming from the lower areas - generally below 5,000 feet.

East Park Reservoir. The East Park dam is in sec. 34, T. 18 N., R. 6 W., Colusa County, on Little Stony Creek, a tributary of Stony Creek which flows into the Sacramento River. The dam is a concrete arch-gravity structure 90 feet high and 250 feet long at its top. The spillway lies about 1,000 feet south of the dam and is a concreted overflow type. The outlet works consist of one 3 3/4 by 5-foot outlet gate and two 42-inch balanced needle valves. The spillway crest level is 1,198 feet above mean sea level. The lake area at that elevation is 1,694 acres, according to

planimeter measurement of the crest contour of the original base map made on a scale of 1 inch equals 500 feet by the U. S. Bureau of Reclamation in 1907. When storage began in December 1910, the original capacity as determined from this survey was 41,098 acre-feet. The reservoir was built for irrigation. A small additional water supply is obtained from a 6-mile long diversion canal from upper Big Stony Creek. The reservoir is at crest level for only a few months during the winter and is drawn down rapidly after June. By late fall the water stage has been lowered approximately 70 percent.

The drainage area, including the lake area, as measured from a U. S. Army Engineer map, is 101.5 square miles. It is hilly to mountainous except for a gently rolling valley above the reservoir. The range in elevation is from about 1,200 to 7,000 feet. Slopes in the mountainous parts often exceed 40 percent; in the foothills 30 percent; and in rolling valley land 15 percent. Precipitation which includes both rainfall and snow ranges from 17 inches at the dam to 55 inches at the highest divide.

The western part of the drainage area is underlain chiefly by metamorphosed sedimentary rocks and includes slates, cherts, serpentine, and quartzites. Hardened shales, shaly sandstones, and conglomerates occur in the eastern part. Soils are relatively thin on the uplands and slopes but usually thick in the valleys. They are principally gravelly and sandy loams.

Native vegetation consists of manzanita, chamise, and scrub juniper with wild oat and bunch grasses forming brushy pasture land. The higher elevations have a fair to good cover of oak, pine, and in spots redwood. The principal land use is for pasturage of sheep. Some valley land is cultivated. Local gullying has occurred near the break in slope between the foothills and valley. Stream-bank erosion is moderately severe. Brush fires have frequently covered much of the basin; hence, sheet erosion is widespread although still moderate in rate.

The reservoir survey was based on a range system tied into shore-line points located on a print of the original contour map. This map prepared in 1907 is exceptionally good and no difficulty was experienced in identifying points. Twenty-one ranges were sounded and spudded. The intervals between spuddings varied from 25 to 100 feet. Lake sediment could be distinguished readily in most cases from the pre-lake bottom, and the survey is considered to be of a high order of accuracy.

The total measured sediment volume of 659 acre-feet was accumulated in 35.2 years. Sediment in the main channel ranges in maximum thickness from 7.4 feet at the dam to 1.0 foot in mid-lake ranges. No pronounced delta exists and the sediment appears to be well distributed. Clays and silt occur only within a few hundred feet above the dam. Fine sands and silty sands are the principal sediment type over approximately three-fourths of the reservoir. The specific weight of 56 pounds per cubic foot is a weighted average of analyses of 13 samples which range from 45.9 to 72.9 pounds per cubic foot. The sediment in the samples varied from 69 percent

clay, 30 percent silt, and 1 percent fine sand to 40 percent sand, 46 percent silt, and 14 percent clay. Organic matter is widely disseminated through the sediment.

The rate of sediment production is moderate and is considered typical of this area.

Exchequer Reservoir. The Exchequer dam is located in sec. 13, T. 4 S., R. 15 E., Mariposa County, on the Merced River. The dam is a concrete-gravity curved structure 305 feet high above stream bed and has a crest length of 960 feet. The spillway crest elevation is 707 feet above sea level, and the original lake area at maximum flow line, elevation 710, as reported by the owners, was 2,720 acres. The spillway is an overflow type. Power is generated and the penstocks have an average outflow of approximately 1,000 c.f.s. The primary use of the reservoir is for irrigation storage. The reservoir is seldom full and then only for a few days after the spring snowmelt. The annual drawdown for irrigation and power amounts to about two-thirds of the total capacity. When storage began in September 1926 the capacity at elevation 710, as determined by the Merced Irrigation District from a topographic survey made on a scale of 1 inch equals 400 feet in May 1922, was 289,000 acre-feet.

The drainage area, as measured by planimeter during this survey on U. S. Geological Survey topographic sheets on a scale of 1 inch equals 2 miles, is 1,027 square miles, including the lake area. Approximately 203 square miles lies in and above Yosemite Park or within small areas that do not contribute sediment. The range in elevation of the drainage area is from 710 to approximately 11,500 feet. Precipitation includes both rain and snow and ranges from 16 inches at the dam to 60 inches on the high divide. Most of the stored water in Exchequer comes from snowmelt, but sediment is transported mainly by runoff from rain. The topography is rough and mountainous. The gradient of the Merced River ranges from 25 feet per mile from Exchequer Reservoir to the lower end of Yosemite Valley to 348 feet per mile above Yosemite. Precipitous slopes characterize most of the drainage above 4,000 feet elevation and steep slopes predominate below 4,000 feet.

Large areas of barren granite out-crop in the eastern drainage area. The western part consists of metamorphics and meta-sedimentaries. Soils are generally absent on the high granite areas but locally are deep in the valleys. The soils are granitic, sandy, and immature. They are highly erodible but are generally well protected by a heavy forest cover of pines and sequoias. Soils of the intermediate elevations are thin. Brush land and oak forests cover much of this area. At lower elevations bedrock is commonly covered by thin sandy loams and gravel. The vegetation is sparse. Wild oats thrive during the spring, and some brush and low trees grow on the hillsides. Ravines and canyons of the lower elevations usually are forested by oak and pine.

Land use is confined largely to grazing and lumbering. A very small area is cultivated. A large area is devoted to recreational use in Yosemite National Park and environs.

The sedimentation survey was based on a system of ranges tied into points shown on the original 1922 contour map of the reservoir. Instrument control was used to space soundings and spuddings. The sediment is confined largely to the channel and an area immediately adjacent to it. Therefore, the ranges were extended only across the sediment deposits. An average of 6 measurements was made on each of 21 ranges. The spacing of measurements varied from 100 to 200 feet and the ranges were spaced from 300 to 9,000 feet apart. Ranges in the delta section, which comprises most of the upper half of the reservoir, were sounded and compared with original profiles plotted from contours of the 1922 map.

A maximum sediment depth of 33 feet was found near the delta front from its top to the original stream bed. The maximum depth of sediment near the dam was 6.2 feet. The sediment is predominantly sand which is interspersed with silt layers. The specific weight of 62 pounds per cubic foot is an average of analyses of 9 samples collected below the delta and proportioned to the volume of delta deposits which were assumed to have a specific weight of 70 pounds per cubic foot. Deposits below the delta comprised 35 percent of the total sediment in the reservoir and averaged 47 pounds per cubic foot.

The total sediment volume of 3,354 acre-feet was accumulated in 19.6 years. Sediment below the delta ranges from 100 percent silt and clay at the dam to 84 percent silt and clay near the toe of the delta front. The delta consists of fine to medium sand with some gravel and occasional silt and clay lenses. Cobbles and even boulders are brought into the upper end of the delta when draw-down permits the stream to entrench itself in the delta.

The rate of sediment production is judged to be about normal for this type of drainage area, but maybe slightly low because natural lakes in and near Yosemite trap some sediment at relatively low elevations. Sediment comes principally from sheet erosion and stream-bank cutting. Mining has furnished only a small quantity of debris and is considered unimportant.

Faulke Lake (False Lake). This reservoir is located in sec. 4, T. 31 N., R. 5 W., Shasta County, on the north fork of Jenney Creek, a tributary of the Sacramento River. It is created by an earth dam, reinforced by hand-placed rock facing on the upstream face. The height above stream-bed level is 21 feet and the crest length is 600 feet. The surface area and original capacity, as determined by this survey, are 18.7 acres and 130 acre-feet, respectively. The spillway, which has a crest elevation of 747 feet, lies 50 feet east of the dam and is excavated in metamorphic rock. This reservoir was built originally for mining use in 1851 and was 94 years old when surveyed. However, mining was abandoned in this area a few years after the reservoir was built, and its principal use since then has been for recreation and stock water. A 3-inch pipe through the dam permits withdrawing a small amount of water for irrigation of a garden plot.

The small drainage area of 0.71 square mile, including the lake surface, was determined from enlarged aerial photographs having a measured scale of 1 inch equals 850 feet. The drainage area is roughly fan-shaped and has two main channel ways. The range in elevation is from 750 to 1,100 feet. The mean annual precipitation is 40 inches, most of which is rainfall. The area is used entirely for pasturing cattle, sheep, and horses. The cover is brushy on lowlands and sparse oak-pine forest at higher elevations. The topography is rolling to hilly with average slopes ranging from 5 percent on the lowlands to 20 percent in the hills.

The rock outcrops are principally meta-volcanics with some slate, serpentine, and schists which are probably meta-sedimentary. Soils are thin, gravelly, and reddish-colored. Remnants of gravel terraces lie in and around the edges of the valley. Channel ways are often grassed, with occasional stretches of bedrock.

The reservoir survey was based on 4 ranges tied into a plane-table triangulation net. Soundings and sediment measurements were controlled by instrument from cut-in stations. The spillway crest contour was mapped on a scale of 1 inch equals 100 feet. The spacing between spud shots was generally 25 feet. Distinction between reservoir sediment and pre-lake bottom was good and the survey is of a high order of accuracy. Sediment, which is well distributed over the reservoir, has a maximum depth near the dam of 3.2 feet. Neither of the two entering streams has formed a delta, and apparently relatively little bed load is being transported into the lake.

The measured volume of 9.4 acre-feet of sediment accumulated during 94 years. It has an average specific weight of 54 pounds per cubic foot, based on analysis of 5 samples ranging from 34.3 to 66.5 pounds per cubic foot. Samples of sediment show a range from 84 percent to 97 percent silt and clay.

The sediment rate is low for this elevation and type of topography. Sediment is derived almost entirely from sheet erosion. Absence of bank cutting and lack of cultivation contribute largely to the low rate.

Gerber Reservoir. This reservoir is located in sec. 33, T. 24 N., R. 4 W., Tehama County, on an unnamed tributary to Burch Creek, which flows into the Sacramento River. The dam is an earth structure 33 feet high above stream-bed level and has a crest length of 840 feet. The spillway at an elevation of 448 feet above sea level lies at the west end of the dam. A 4-inch pipe leads through the dam to an irrigation system built to irrigate about 50 acres of alfalfa. The system was not functioning at the date of the survey. The primary purpose for building the reservoir, however, was stock water. An older dam about 10 feet high was located about 200 feet below the present structure and at the junction of this tributary and Burch Creek. It was undercut by bank scour and failed shortly before the present dam was built. As determined by this survey the surface area and original capacity at spillway crest were 17.0 acres and 190 acre-feet, respectively, when storage began in June 1917. The reservoir goes dry almost every summer and sheep trample the sediment before it dries out.

The drainage area, including the lake area, is 0.31 square mile (198 acres), as determined from aerial photographs having a measured scale of 1 inch equals 676 feet. The range in elevations is from 448 to 550 feet. Annual precipitation in the form of rain averages 19 inches. The drainage area lies on and in a gravel terrace incised rather deeply by two tributaries supplying Gerber pond. The upland divide is almost flat in contrast to the steep slopes leading from its edge to the stream channels. The cover is scanty and consists of short grasses. The entire area is grazed heavily by sheep.

The soils are thin gravelly loams except in swales where they are thicker and contain more silt and clay. The bedrock material is unconsolidated gravel, the top of which is commonly cemented by caliche to form a resistant zone approximately 8 inches thick. This forms a semi-protective capping which maintains a sharp angle between the terrace top and the down-cutting valley. If erosion cuts through the caliche cap it goes rapidly. The head of the valley is a group of deeply cut lobate gullies. Sheep trails often start gullies near the terrace rim. The channels are bank-cutting and deepening.

The reservoir survey was based on 6 ranges tied to a plane-table triangulation net. Soundings and sediment measurements were controlled by instrument from cut-in stations. The spillway crest contour was mapped on a scale of 1 inch equals 100 feet. Sediment measurements on the ranges were spaced 25 feet apart. Distinction between sediment and original bottom was good and the survey is of a high order of accuracy. The measured volume of sediment of 7.8 acre-feet accumulated during 28.5 years. The mean specific weight of 78 pounds per cubic foot is based on analysis of 5 samples which ranged from 68.3 to 92.5 pounds per cubic foot. The high average weight of the sediment is explained by repeated exposure to drying and compaction by trampling of animals. The mechanical analyses showed a range from 97 percent silt and clay in the channel near the dam to 50 percent silt and clay near the edge of the pond outside the channel. This latter sample contained 21 percent gravel.

The sediment production rate for the Gerber drainage area was the highest measured during this investigation. It is a result of overgrazing, scanty natural cover, and erodible soils.

<u>Gilmore Reservoir</u>. This reservoir is located in sec. 9, T. 2 N., R. 9 E., San Joaquin County, on a tributary to Mormon Slough, which is in the lower part of the Calaveras River drainage basin. The earth-fill dam is 28 feet high above stream-bed level and has a crest length of 1,080 feet. The spillway is a rock and concrete sill 107 feet long on the north end of the dam. It is 6.0 feet below the top of the dam and is 219 feet above mean sea level. When storage began in September 1917, the surface area of the reservoir at crest was 58.2 acres and the original capacity was 579 acre-feet, as determined by this survey. The reservoir was built for irrigation and stock water. Two 16-inch gate valves - one on each side of the dam - are used for releasing water. One-foot flash

boards were used before 1931 and some difficulty was experienced with spillway erosion. The original spillway was lowered 2 feet in 1932. When first built, the dam leaked considerably. This condition was corrected by facing the upstream side with clay. The water stage is usually at or near crest from January to May, but is drawn down until the basin is nearly empty at the end of each summer. Wave action is considerable during windy months.

The drainage area, including the reservoir surface, is 5.0 square miles, as determined from enlarged aerial photographs having a scale of approximately 1 inch equals 500 feet. The topography is moderately to steeply rolling near the lake and gently rolling at higher elevations. The highest elevation in the area is approximately 325 feet. The area covers a gravelly terrace into which the main stream and two minor tributaries have been cut. Soils are thin and gravelly. Bank erosion occurs intermittently along the channels. Most of the channelways have been dredged for gold and the spoil gravel returned to the bed. This has produced hummocky, partially obstructed waterways. The land surface is marked by numerous sheep trails. The swales are grassed by wild oats and small bushes. Scrub trees are sparsely distributed on the slopes. The annual precipitation averages 19 inches and consists wholly of rain. The drainage area is used exclusively for sheep grazing.

The reservoir survey was based on 8 ranges tied into a plane-table triangulation net. Soundings and sediment measurements were controlled by instrument from cut-in stations. Soundings were taken at intervals of approximately 25 feet and sediment measurements every 75 or 100 feet. The shore line was traced with field checking from aerial photographs on a scale of approximately 1 inch equals 500 feet. Distinction between sediment and original bottom was good and the survey is rated as of a high order of accuracy. The total measured sediment volume of 18.2 acre-feet was deposited in 28.0 years. The maximum sediment depth ranged from 1.3 feet at the dam to 1.5 feet two-thirds of the distance to the upper end. The maximum depth on the uppermost range was 0.6 foot. The distribution of sediment is rather uniform over the lake bottom near the dam but is more restricted to the channel section near mid-lake. The delta is not sharply defined but appears to extend and thicken toward its front which lies about 1,500 feet from the upper end of the reservoir. The weighted mean specific weight of 50 pounds per cubic foot is based on analysis of 5 samples which had a range from 35.3 to 70.9 pounds per cubic foot. The silt and clay content varied from 96 to 100 percent in 4 samples and was 90 percent in a sample from the delta.

The sedimentation rate for the Gilmore drainage area is low. The dredged gravel left in the channels appears to be an effective sediment trap. The Davis drainage area which is adjacent to Gilmore is similar in all ways except that no dredging was done. The measured sedimentation rate for Davis Reservoir is 2.4 times that of Gilmore Reservoir.

Hume Reservoir. This reservoir is located in sec. 14, T. 13 S., R. 28 E., Fresno County, on Ten Mile Creek, a tributary of Kings River. The dam is a multiple-arch concrete structure, said to be the oldest of its type in California. It has a total height of 60 feet, a crest-to-stream-bed height of 48 feet, and a crest length of 650 feet. The original capacity, as reported by the U. S. Forest Service from a map made by that agency on a scale of 1 inch equals 200 feet, was 1,410 acre-feet, and the surface area at crest elevation 5,300 feet was 85.2 acres. The spillway is an overflow type. It spills water for approximately 4 months each year, but the average depth of flow seldom exceeds 0.5 foot. Constructed originally by the Sanger Lumber Company for use in lumbering operations and put in service in 1909, it was acquired by the U. S. Forest Service in 1935 and developed for recreational uses. In 1940 the lake was drained in order to make repairs to stop leakage through the dam. At that time the outlet valve at the base was blocked by a one-foot depth of fine sand and silt. Photographs taken in 1940 show approximately one foot of sediment accumulated on the bottom of the lake for about one-fourth of the length of the dam.

The drainage area, including the reservoir surface, as determined from planimetering U. S. Geological Survey topographic sheets, is 24.2 square miles. The area is mountainous and ranges in elevation from 5,300 to nearly 8,000 feet. It is completely forested by pines and oaks. It was cut over several decades ago and some parts have been burned; thus the present cover is almost wholly second growth. The underlying bedrock is largely meta-sedimentary and meta-volcanic rocks on which fine sandy loams have developed. These soils are relatively erodible if unprotected, but are generally well stabilized in this drainage area by the forest cover. The predominantly steep slopes have a good pine needle mat on them. Precipitation consists of both rain and snow and ranges between 35 and 40 inches per year.

The reconnaissance survey made on Hume Reservoir was based on 4 ranges. The position of sediment measurements was estimated visually. From these data it was estimated that 27.2 acre-feet of sediment had accumulated in 37 years. The maximum sediment thickness ranges from 1.1 feet at the dam to 1.6 feet on the uppermost range. The gradation is uniform and no sharply defined delta exists although most of the sediment lies in the upper half of the reservoir. The sediment is chiefly silty fine sand. An assumed average specific weight of 62 pounds per cubic foot was used to compute tonnage of sediment.

The sediment-production rate is low for this type of reservoir. Sediment is derived mainly from sheet and channel erosion. Because of the erodible nature of the soils a higher production rate can be expected if the cover is removed or altered. Although a considerable length of surfaced roads have been built around the lake they do not appear to be causing much erosion.

Kerckhoff Reservoir and Dam No. 6. Kerckhoff Reservoir in sec. 24, T. 9 S., R. 22 E., and Big Creek Dam No. 6 in sec. 27, T. 8 S., R. 24 E., are both located on the San Joaquin River in Fresno and Madera Counties. The Kerckhoff dam is a variable-radius arch concrete structure 83 feet high above stream-bed level and 545 feet long at crest elevation 971.3 feet above mean sea level[6]. Its original capacity when storage began in 1920, as reported by the Pacific Gas and Electric Company, was 4,200 acre-feet[6]. The reservoir serves as a forebay and diversion structure for power generation. Big Creek Dam No. 6 is a constant-radius arch structure 130 feet high above stream-bed level and 364 feet long at crest[6]. Its original capacity was 993 acre-feet at crest elevation 2,230 feet above mean sea level when storage began in 1923, as reported by the California Edison Company[6]. The reservoir is used as a forebay and diversion for power generation.

Surveys of both reservoirs were made by personnel of the U. S. Forest Service[14]. Kerckhoff Reservoir was surveyed in November 1939 when it was drawn down for repairs on the dam. Profiles were taken along range lines and tied into a plane-table triangulation net. The original surface elevations were plotted on the profiles from the original contour map of the reservoir basin made by the Pacific Gas and Electric Company. From the difference in cross-section areas of the profiles the sediment volume was computed. Dam No. 6 was surveyed by hand-level measurements across selected ranges during a period of draw-down in October 1940. The original contour map was used to compare changes in levels.

Computation of the combined sediment volume in Kerckhoff Reservoir and Dam No. 6 is complicated by various sluicing operations. The computation of sediment volume (1,152 acre-feet) in Kerckhoff Reservoir in November 1939 is considered by Forest Service engineers to be accurate within approximately 5 percent. In addition, during this survey it was estimated from dimensions of the channel through the sediment deposits that approximately 400 acre-feet had been scoured out of the reservoir during draw-down just preceding the survey. Thus, the total volume before draw-down was 1,552 acre-feet. Dam No. 6 was sluiced in December 1938, October through December 1939, and again in October 1940 before the survey made on October 18, 1940. The surveys indicated that sluicings in 1938 and 1939 removed 284 acre-feet, an estimated half of which was removed each year. The California Edison Company reports the total sluicing for the three years as 458 acre-feet. Only the material sluiced in 1938 - 142 acre-feet - is believed to have reached Kerckhoff Reservoir by the time it was surveyed in November 1939. The remaining 316 acre-feet sluiced in 1939 and 1940 was then behind Dam No. 6 except such part as may have been deposited in these years. In the present analysis it is assumed that the amount deposited in these two years offsets the amount left in the reservoir after the 1940 sluicing. Therefore, the total deposit in 1939 was 316 acre-feet. This volume added to the 1,552 acre-feet in or sluiced from Kerckhoff gives a total of 1,868 acre-feet of deposits in the two reservoirs in 19 years (1920-1939).

Using the total original storage of both reservoirs and the weighted average net drainage area, the trap efficiency was estimated from Figure 3 to be 45.5 percent. The specific weight of 70 pounds per cubic foot was assumed, consideration being given to the frequent draw-down, drying and compaction, and to the low trap efficiency which allows much of the finer sediment to pass through the reservoirs.

The determination of net effective drainage area is complicated by the construction of upstream reservoirs at various dates since the completion of Kerckhoff Reservoir (1920) and Dam No. 6 (1923). The gross drainage area above Kerckhoff dam is 1,460 square miles[(6)]. The net sediment-contributing area in 1920 was 1,320 square miles, excluding the area above Manzanita Dam and Crane Valley Reservoir (61 square miles) and above Huntington Lake (79 square miles). Construction of Florence Lake in 1926 excluded another 171 square miles, and Shaver Lake in 1927 another 30 square miles. The net drainage area, therefore, was 1,320 square miles for 6 years, 1,149 square miles for 1 year, and 1,119 square miles for 2 years, or a weighted mean of 1,184 square miles for the 19-year period of record.

The drainage area is similar in many respects to those of other large reservoirs on the western slope of the Sierra Nevada. The range in elevation is from 971 to 13,000 feet. The terrain is rough and mountainous and slopes in excess of 40 percent predominate. Precipitation consists of both rain and snow and varies from 16 inches at Kerckhoff dam to 50 inches on the highest divide. The bedrock ranges from metamorphics and meta-sedimentaries in the western part to granites and granodiorites in the central and eastern parts. Much bare granite is exposed above 4,000 feet elevation. Soils developed on the metamorphics are thin loams. Soils on granite are sandy loams and granitic gravelly loams, which are very erodible when unprotected. However, much of the drainage area, particularly at the highest elevations, is devoid of soil cover. The middle elevations have a good cover of pine forest. Some lowland valleys are grassy and are used principally for grazing. Lumbering is done in several places in the timber belt. Roads are few and confined mostly to the lower western part of the area.

The sediment-production rate is moderate and comes principally from sheet and stream-bank erosion.

<u>La Grange Reservoir</u>. This reservoir is located in sec. 16, T. 3 S., R. 14 E., Stanislaus County, on the Tuolumne River. The reservoir is created by a gravity-curved masonry dam 120 feet high above stream bed and 310 feet long at crest. The spillway is an overflow weir having an elevation (in 1905) of 299 feet above sea level. The reservoir is in a precipitous canyon above the dam and has a low ratio of capacity to drainage area. The dam is reported to have been constructed in 1894[(6)] to divert the Tuolumne River into the Turlock and Modesto Irrigation District canals. The dam was constructed with an opening 4 feet wide by 5 feet high near the bottom and in the early years of its history the

low flow of the river is reported to have passed through this opening when water was not needed for irrigation(13).

The drainage area is reported by Lippincott(13) to be 1,501 square miles. A general description of the drainage area is given under the heading Don Pedro Reservoir in this Appendix.

A contour survey of La Grange Reservoir was made in September 1895 by J. P. Lippincott for the U. S. Geological Survey. Ten-foot contours were mapped. The surface area at elevation 300, one foot above the 1905 crest of the dam, was 56.1 acres and the capacity at this elevation was computed to be 2,332 acre-feet. In October 1905 a second contour survey was made by Edward Johnson for the U. S. Geological Survey. This survey showed a surface area of 54.1 acres and a capacity of 1,068 acre-feet at elevation 300. Thus, the indicated sediment volume was 1,264 acre-feet which represented a capacity loss of 54.2 percent in 10.1 years(13).

The trap efficiency of 41.9 percent was determined by comparison of rates of sedimentation in La Grange and Don Pedro Reservoirs. This is based on the assumption that rates of sediment production from the drainage area were comparable during the periods 1895-1905 and 1923-1945. There are no apparent reasons why this assumption is not valid. The specific weight of 70 pounds per cubic foot is an assumed value based on the frequency of draw-down, with consequent drying of sediment, and the low capacity/drainage area ratio which allowed much of the finer sediment to pass over the spillway.

Lyons Reservoir. This reservoir is in sec. 24, T. 3 N., R. 16 E., Tuolumne County, on the South Fork of the Stanislaus River. The dam is a variable-radius arch concrete structure 115 feet high above stream-bed level and 500 feet long at crest. The spillway, of overflow type, is at elevation 4,220, and the lake at crest has a surface area of 197 acres. When storage began in June 1930, the capacity, as determined by engineers of the Sierra and San Francisco Light and Power Company (now owned by Pacific Gas and Electric Company), was 5,500 acre-feet. This capacity was determined by planimetering the 10-foot contours of the original base map, which has a scale of 1 inch equals 500 feet. Water is released by two gate valves near the base of the dam. The reservoir was built for power and irrigation storage. Prior to construction of the present dam, a log crib structure 15 feet high impounded water at this site for several years.

The drainage area, including the surface of the reservoir, as planimetered from U. S. Geological Survey quadrangle sheets, is 40.0 square miles. This does not include the drainage area above Strawberry Reservoir which is upstream from Lyons. The range in elevations is from 4,220 to 9,300 feet. Precipitation consisting of both rain and snow ranges from 42 inches at the dam to 50 inches at the upper end of the drainage basin. The bedrock consists of marine meta-sediments in the western part and granites and andesite in the central and eastern parts.

Soils on the meta-sedimentary rocks are thin loams; soils on granite and andesite are sandy and gravelly loams or clays. The topography is rough and mountainous. Slopes are steep and have little soil cover. The higher elevations are heavily forested by pines. Grazing and lumbering are the only land uses in the drainage area.

The reconnaissance sedimentation survey was based on 5 ranges distributed uniformly over the length of the reservoir. From 3 to 5 sediment thickness measurements were made on each range with a spud. The spacing of measurements was estimated visually. The estimated volume of 64.1 acre-feet of sediment accumulated during a 16-year period. An average specific weight of 70 pounds per cubic foot was assumed because of the sandy character of the sediment. Distinction between lake sediment and older pre-lake channel deposits was difficult in places. A maximum depth of 1.2 feet of sediment occurred on the uppermost range about three-fourths of the distance from the dam to the upper end of the reservoir. At the dam the greatest measured depth of sediment was 0.8 foot. Sediment is confined almost entirely to the original stream channel within the reservoir area. A delta is forming from about midway to the upper end of the lake.

Sediment production is chiefly from sheet and stream-bank erosion.

Magalia Reservoir. This reservoir is in sec. 25, T. 23 N., R. 3 E., Butte County, on Little Butte Creek, a tributary of Big Butte Creek, which flows into the Sacramento River. The dam is a hydraulic earth-fill structure with hand-placed riprap on the upstream face. It is 90 feet high above stream-bed level and is 850 feet long at the crest. The spillway is located at the east end of the dam and has a sill elevation of 2,234 feet above mean sea level. It is concrete-lined and has provisions for 6-foot flash boards. An outlet valve near the center of the dam permits irrigation water to enter a 3-foot diameter pipe line. At crest elevation the surface area is 100.4 acres, and the original capacity, when storage began in January 1918, as determined by this survey, was 3,718 acre-feet. The reservoir was constructed for irrigation storage. It is drawn down each summer to about half of its total depth. It is reported to have been almost dry at times. The crest stage is usually not reached until January and water rarely spills more than 3 or 4 months. Water use and demand are heavy and it is reported that plans are being made to increase the height of the dam.

The drainage area, including the reservoir area, but excluding approximately 3 square miles of non-contributing drainage above a canal in the upper part of the area, as determined from aerial contact photographs on a scale of 1 inch equals 1,667 feet, is 8.2 square miles. Elevations range from 2,234 to 3,600 feet. The topography is mountainous and steep slopes prevail, but the valley for 3 miles above Magalia has a narrow floodplain on which there are a few farm houses and orchards. The uplands are densely forested by pine. Some parts are grazed by cattle and sheep. The cover is good, owing in part to the high annual

precipitation which ranges from 77 inches at the dam to 80 inches on the northern divide. Snow falls occasionally during January to March but it is not as important quantitatively as rainfall. An open canal crossing the upper end of the drainage area intercepts the drainage of 3 square miles which would otherwise enter Little Butte Creek. Small-scale mining activities and occasional forest fires have accelerated the sediment-production rate.

The bedrock is principally marine meta-sediments in the northern part and terrestial gravels in the southwestern part of the drainage area. A zone of serpentine and schist trending from north to south occurs in the southeastern part. The soils are reddish gravelly loams and clays. Gravel beds are exposed in the lower elevations. Soils in the valleys and on the lower slopes are moderately thick, whereas upland soils are thin but well protected by a mat of pine needles.

The sedimentation survey was made by the range method based on a control net previously established in a survey made by the Paradise Irrigation District. A field check of the marked stations of the previous survey indicated a high degree of accuracy in their map, which has a scale of 1 inch equals 200 feet. Seven ranges were sounded and spudded at approximately 25-foot intervals. The computed sediment volume of 69.5 acre-feet accumulated during 28 years. The specific weight of 49 pounds per cubic foot is an average of analyses of 5 samples which ranged from 35.5 to 62.5 pounds per cubic foot. The silt and clay content of these samples ranged from 64 to 98 percent. Distinction between reservoir sediment and the pre-lake bottom was readily made and the survey is classed as of a high order of accuracy. The distribution of sediment is fairly uniform with no distinct delta formation. A maximum sediment depth of 4.0 feet was found near the dam in the channel, and the remainder varied from 1.2 to 1.9 feet. Near the dam the predominant sediment was light gray silt but the middle and upper parts of the reservoir contained fine silt grading to silty fine sand. Organic matter such as twigs, leaves, and bark was abundant and widely distributed.

Sediment production from this drainage area is largely from sluice-box mining and stream-bank and near-channel gully erosion. Sluice-box mining, which is popularly called "sniping," was widespread during the depression years between 1930 and 1937. The combination of many individual operators and the heavy rainfall during the winter season produced an unusually high rate of transportation of the mining debris. In addition to sniping there is some gully activity on old orchard sites and along abandoned roadways.

McCarty Reservoir. This reservoir is located in sec. 18, T. 2 N., R. 12 E., Calaveras County, on a tributary to Johnny Creek which is in the drainage basin of Littlejohns Creek. The dam is of earth fill with rock and earth facing and is 17.5 feet high above stream-bed level and is 738 feet long. The spillway is 14.5 feet above the stream bed and has an elevation of 1,147 feet above sea level. The surface area of the reservoir is 16.8 acres, and the original capacity, as determined by this

survey, was 96 acre-feet when storage began in December 1937. An older earth dam 4 feet high existed on the site for several years before the present structure was built. A 5-inch pipe controlled by a valve runs through the dam at the channel axis and is used for withdrawal of water. The principal use of the reservoir is for stock water with some use for irrigation. Summer and fall usage reduces the supply to less than half of the capacity. The spillway, which is a rock-lined structure, carries water on an average of only a month or two each year.

The drainage area, including the surface area of the lake but excluding the drainage above an upstream stock pond, is 225 acres (0.35 square mile), as measured on two enlarged aerial photographs which have field-determined scales of 1 inch equals 526 feet and 440 feet. The topography is gently rolling upland valley with a hilly border on the east side. Slopes are low to moderate. The elevation ranges from 1,150 to 1,700 feet. Precipitation is chiefly rainfall which averages above 21 inches annually. The area is used entirely for pasturage of cattle, horses, and sheep. The valley section, comprising about 80 percent of the total area is open and well grassed. During winter and spring it supports a tall stand of wild oats. Summer and fall months are dry and at that time the cover deteriorates rapidly. The hilly section is wooded by oaks and scattered pines.

The bedrock consists of marine meta-sediments and basin meta-igneous rocks. Valley soils consist of fine sandy loams and clay loams. The hilly slopes and uplands have thin, patchy loams developed on them.

The reservoir survey was based on 4 ranges tied to a plane-table triangulation net on a scale of 1 inch equals 100 feet. The crest contour was mapped on a scale of 1 inch equals 200 feet. Spacing of sediment measurements on ranges averaged 25 feet apart. The survey is classed as having a high order of accuracy. The measured sediment volume of 0.74 acre-foot accumulated during 7.7 years. No samples were collected for determination of specific weight because the sediment depth was nowhere sufficient to permit use of the sampling device. However, the extreme fineness of deposits and absence of sand indicated that the specific weight should be approximately 45 pounds per cubic foot. The maximum sediment depth of 0.9 foot was recorded at one station in the channel on the uppermost range. The range nearest the dam had a maximum sediment depth of 0.1 foot. Distribution is rather uniform over the entire reservoir bottom.

The sediment-production rate is relatively high for this region. Much of the sediment appears to come from channel scour and sheet erosion during the early part of the rainy season. Later the growth of vegetation halts the more active sheet erosion and parts of the channelways become grass-covered.

Misselbeck Reservoir. This reservoir is located in sec. 31, T. 31 N., R. 7 W., Shasta County, on the North Fork of Cottonwood Creek, a tributary of the Sacramento River. The dam is a hydraulic-fill structure 110 feet

high above stream-bed level with a crest length of 1,035 feet. The surface area is 115 acres, and the original capacity when storage began in May 1920, as reported by the Happy Valley Water Company, was 4,300 acre-feet(6). This figure was obtained by planimetric measurement of contours from a base map of uncertain accuracy made on a scale of 1 inch equals 100 feet. The spillway is a concrete-lined structure 100 feet wide cut through bedrock at the west end of the dam. At present it has a timber structure 4.5 feet high built on the concrete spillway sill. This raises the crest level to elevation 2,190.5 feet, but the structure is not considered permanent. Two outlet pipes 36 inches in diameter and controlled by valves lead through the dam near the east end. The reservoir was constructed primarily for irrigation storage. It is drawn down to about one-fourth of its capacity by irrigation demands during summer and fall. The owners attempt to lower the stage further by water release during the early winter, partly in an effort to flush out sediment and partly to make available storage space to prevent excessive overflow through the spillway in the spring. The reservoir overflows only for a month or two during spring. Intense storms sometimes cause heavy flow over the spillway and produce considerable erosion at its base.

The drainage area of 12.0 square miles, including the surface area of the reservoir, was determined by engineers of the California Division of Water Resources(6). The topography is steep and rugged. Slopes generally exceed 40 percent over most of the drainage area, which ranges in elevation from 2,200 to approximately 7,000 feet. Precipitation consists of both rain and snow and ranges from 50 inches at the dam to 60 inches on the western and northern divides. The entire area is forested by pine. It is a primitive wildlife area, uninhabited except for a few cabins along the lake shore. There are no roads and few trails. The bedrock is mostly granite which is deeply decomposed and potentially highly erodible. A small band of basic meta-igneous rocks out-crops in the lower southeastern part of the area. Soils are thin except in the bottoms of the narrow valleys. Over much of the steep slopes soil is absent.

The reservoir survey was a reconnaissance type based on 5 ranges tied into the original base map by estimating distances from the prominent spurs shown on the map. Four of the ranges were sounded at 10- to 25-foot intervals; the profile of the uppermost, which was not inundated, was measured by level and tape. Because of the coarse texture of the sediment and lack of distinction from the pre-lake bottom, the spud could not be used for direct sediment measurement. The original profile was plotted for each range from the 10-foot contours of the original map. On these profiles were plotted the results of the soundings. The cross-section area inclosed by the original and new profiles was planimetered and the average sediment depth obtained by dividing the crest length of the range by its cross-sectional area. The volume of sediment between two ranges was obtained by multiplying the average mean depth of sediment on the bounding ranges by the surface area between them. The results obtained are considered fair. The accuracy is limited mainly by uncertainty about some parts of the original map.

The computed sediment volume of 214 acre-feet accumulated during 25.5 years. The maximum sediment depths on each range from the dam to the head of the lake were 8.5, 7.0, 8.5, 15.0, and 22.5 feet, respectively. The delta deposits consist of granitic sand interspersed with fine gravel. Fine sand and silty fine sand are predominant from the toe of the delta to about mid-length of the reservoir. Fine sandy silt grading into silt occurs from mid-length of the reservoir to the dam. The original channel appears to contain somewhat coarser sediment than occurs on either side. Silt layers a few inches thick are interbedded with medium and coarse sand in the delta front. The delta is sharply defined from its head to the front or foreset beds. Only one sample from the delta was obtained for specific-weight determination. The sandy character of the sediment prevented adequate penetration or else sediment failed to hold in the sampling nipple. A specific weight of 75 pounds per cubic foot was assumed from the nature of the sediment. The delta sample contained 5 percent silt and clay, 55 percent sand, and 40 percent fine and medium gravel.

The sediment-production rate at Misselbeck is high for a mountainous, forested area. The source is decomposed granite which is exposed on very steep slopes and in channels. Much granitic sand and gravel is loosened by temperature changes and moves by gravity down the slopes into the channels. The channelways themselves scour deeply into the loose bedrock.

Pardee Reservoir. This reservoir is located in sec. 26, T. 5 N., R. 10 E., Amador and Calaveras Counties, on the Mokelumne River. The dam is a concrete-gravity curved structure 350 feet high above stream-bed level and 7.5 feet above the permanent spillway sill which has an elevation of 567.5 feet above mean sea level. The main spillway is an off-channel concrete structure located south of the dam. A supplemental spillway lies 2 miles north of the dam. The surface area of the reservoir is 2,250 acres. When storage began in 1929, the original capacity, as reported by L. S. Hall, engineer of the East Bay Municipal Utility District, was 210,000 acre-feet[10]. Outlets through the dam consist of two 72-inch diameter tunnels, two 42-inch diameter tunnels, and two penstocks from the 72-inch diameter tunnels. The reservoir was constructed for municipal water supply but is also operated for electric power generation. Water stage fluctuates widely according to season and water demand. A range of 50 feet in water stage during one season is not exceptional. In very dry seasons the reservoir does not reach spillway level. Large areas of sediment on the delta are exposed almost annually.

The drainage area, including the reservoir surface but excluding the drainage area above Salt Springs, Bear, and Tiger Creek reservoirs, is 384 square miles, as reported by the East Bay Municipal Utility District[6], with subtractions for upstream reservoirs[6]. The topography is mountainous and ranges in elevation from 568 to over 10,000 feet. The bedrock consists of shales and slates cut by intrusive basic igneous rocks in the western part of the area; basic lava capped by granodiorite in the central part; and granite with granodiorite in the eastern and highest parts. Soils

developed on these rocks are residual, thin on upland slopes, and locally thick in valleys. Soils of the granite areas are immature and contain much detrital rock and gravel. Large areas of bare granite occur in the higher parts of the drainage basin. Pine forests are conspicuous above 4,000 feet and mixed pine and oak grading to predominantly oak woodland occur below 4,000 feet. The drainage area is used chiefly for grazing and lumbering, but it also includes small urban and cultivated areas of the valleys, and some mining activities.

Precipitation consists of both rainfall and snow. It ranges from 23 inches at Pardee dam to 60 inches on the highest divides.

Two sedimentation surveys were made by personnel of the East Bay Municipal Utility District. The first survey was made in 1939, and a partial resurvey, covering the upper part of the reservoir, was made in August 1943. Both surveys were made by the range method following the procedures of the Soil Conservation Service(7). Altogether 26 ranges have been established, sounded, and in part spudded. As the 1943 survey covered only the upper part of the reservoir, it was necessary to estimate accumulation in the lower part of the reservoir by applying the same rate of increase in sediment volume determined for the upper part between surveys to the lower part. The total volume of sediment in August 1943 was thus computed to be 817 acre-feet, which represents an accumulation of 14 years. Approximately 65 percent of the sediment had accumulated in the delta area. The delta extends down the lake about half the distance to the dam. The lower part of the lake, containing the remaining 35 percent of the sediment, consists of two long arms which join each other at the junction with the upper lake and at an angle of approximately 90 degrees to it. The lake is thus roughly "T"-shaped. A maximum depth of sediment of 31 feet was recorded on a narrow range near the front of the delta. Other maximum depths on delta sections ranged from 16.5 to 24 feet. On the lower lake ranges sediment thicknesses were from 1.2 to 5.0 feet. A specific weight of 62 pounds per cubic foot was assumed based on the similarity of the Pardee sediment to that of Exchequer for which specific weight analyses were made.

The sediment-production rate for Pardee is relatively low. Sediment comes chiefly from stream-bank and sheet erosion.

Salt Springs Valley Reservoir. This reservoir is in sec. 16, T. 2 N., R. 11 E., Calaveras County, on Rock Creek, a tributary of Littlejohns Creek. It is formed by a rock-faced earth dam with an over-all height of 45 feet above the stream bed and a crest length of 2,000 feet. The spillway crest elevation is 4.6 feet lower than the top of the dam, or 1,173.4 feet above mean sea level. The surface area at crest is 1,195 acres, and the capacity as reported by the owners was 12,930 acre-feet(6). The reservoir was constructed in 1882. The spillway was cut into rock on the south end of the dam. One outlet gate in the dam delivers water to a canal. The reservoir was built originally for mining use but for several years has been used for irrigation storage. Information was not obtained

on fluctuation of water levels, but it is probably seasonal and dependent on demand and rainfall.

The drainage area, including the reservoir surface, as determined by planimeter from U. S. Geological Survey topographic sheets, is 20.3 square miles. The area is nearly round and bowl-shaped with gently rolling valley land near the center, ending abruptly near the outer edge in steep sloping hills and low mountains. The range of elevations is from 1,173 to approximately 2,500 feet. The valley is well grassed and is used for grazing. The relatively small area of foothill slopes is brushy and has a few scattered oaks and pines at the higher elevations. Precipitation is mainly rain which averages about 20 inches annually.

Bedrock underlying the area consists of terrestial shales and calcareous sediments in the western part and basic meta-volcanic rocks in the eastern part. Soils developed in the valley are moderately deep loams and sandy loams. Soils on foothills and steep slopes are thin loams.

The reservoir survey was a reconnaissance type. Ten sediment measurements were taken with a spud over the lake basin. The original and present water depths at these points of observation were totaled. The difference divided by the original depth was 1.8 percent, which is equivalent to the loss of capacity if the observations represent a true sample. This percentage loss applied to the original capacity indicates a sediment volume of 233 acre-feet, accumulated during 63 years. A specific weight of 50 pounds per cubic foot was assumed based on the fine texture and easy penetration of the sediment. The sediment distribution is relatively uniform throughout the reservoir. No delta was observed. Distinction between sediment and pre-lake bed material was easily made.

The sediment-production rate is moderate. Sediment probably comes mainly from sheet erosion. Much potential sediment is trapped as colluvium at the break in slope between foothills and valley. The well-grassed valley floor is effective in preventing gully formation.

Stony Gorge Reservoir. The Stony Gorge dam is in sec. 16, T. 20 N., R. 6 W., Glenn County, on Stony Creek, a tributary to the Sacramento River. The dam is a concrete Ambursen-type structure 120 feet high above the stream bed. The crest length is 868 feet. The lake area at the spillway elevation 841 feet above mean sea level is 1,292 acres. The original capacity, when storage began in November 1928, as determined by this survey, was 48,889 acre-feet. The spillway is an overflow weir centered over the stream channel. The outlet works consist of two 42-inch balanced needle valves about 9.5 feet above the stream channel. Water stages fluctuate widely over a range of about 50 feet each season. The reservoir was built for irrigation use and demand is heavy. It is partially regulated by releases from East Park Reservoir which lies upstream. In dry years the reservoir is not filled and in normal or even wet seasons the water depth over the spillway rarely exceeds 1 foot.

The drainage area, including the surface area of the reservoir, but excluding the drainage area above East Park dam, is 199 square miles, as determined by planimeter measurements from a Corps of Engineers map (Index 8, Sacramento Valley-Pittsburg to Headwaters). The topography is mountainous with steep to precipitous slopes along the western and eastern edges, with steeply rolling to gentle slopes in the valley. Elevations range from 841 to over 7,000 feet. Bedrock underlying the drainage area consists principally of shales, slates, cherts, and shaly sandstones. The valley floor is rather deeply filled by sands, gravels, and conglomerate. Soils are thin and rocky on the uplands and steep slopes. Valley soils are gravelly and variable from thin to locally thick. Precipitation includes both rain and snow and varies from 18 inches at Stony Gorge dam to 55 inches annually on the highest divide on the west side.

The mountain slopes are moderately well forested by pine and occasional redwood. Intermediate elevations support oak, manzanita, and high brush; low elevations, including the valley floor, are sparsely brushy, with willows, cottonwoods, and tules growing in places. The flatter slopes are fairly well grassed. Most of the valley and foothill area is used for range land to graze cattle and sheep. An estimated 10 percent of the area is cultivated.

The reservoir survey was based on 13 ranges, which were located between prominent shore-line indentations that could be readily identified on a print of the original contour map prepared by engineers of the U. S. Bureau of Reclamation in January and February 1925 on a scale of 1 inch equals 400 feet. The soundings and spuddings were spaced from 25 to 50 feet apart, depending on the length of the range. Distinction between sediment and pre-lake bottom materials was good and the survey is classified as of a high order of accuracy. The measured volume of 670 acre-feet of sediment was accumulated in 17.3 years. The average specific weight of 54 pounds per cubic foot was obtained from analyses of 6 samples, which had a range from 33.4 to 71.1 pounds per cubic foot. The silt and clay content of the samples varied from 55 to 100 percent; sand from 0 to 45 percent. The maximum sediment depth of 7.3 feet occurred in the channel section of the second range above the dam. At mid-length of the reservoir the maximum depth was 4.0 feet. No clearly defined delta was recognized, but the average grain size of the sediment increased progressively from fine clayey silt at the dam to silty fine sand near the head of the reservoir.

<u>Upper Bear River Reservoir</u>. This reservoir is in sec. 9, T. 8 N., R. 16 E., Amador County, on the Bear River. The dam is a rock-fill dry masonry type 75 feet high above stream bed and has a crest length of 748 feet. The spillway is an overflow type and is 5,874 feet above mean sea level. The surface area of the reservoir at spillway crest is 164 acres, and the original capacity, as reported by the Pacific Gas and Electric Company, was 6,712 acre-feet(6) when storage began in September 1900. Water is released through gated outlets which are controlled by valves. The reservoir was built for reservoir storage to supplement downstream flow

during the dry summers. Fluctuation of level is not great, although the reservoir falls a few feet below crest during the summer and fall months.

The drainage area, including the reservoir surface, as measured by planimeter on U. S. Geological Survey topographic sheets, is 28.5 square miles. The topography is rough and mountainous, with many very steep to precipitous slopes. The upper Bear River and its principal tributary, Tragedy Creek, occupy deeply incised canyons in which there are no flood-plain areas. Elevations range from 5,874 to over 9,000 feet. The area is a wild primitive region virtually uninhabited and almost inaccessible above the dam. Precipitation consists of rain and snow, of which snow is probably more important quantitatively. The mean annual precipitation ranges from 56 inches at the dam to 70 inches at the top of the northeastern divide.

The entire drainage area is underlain by granite except the rim of the divide which is capped by andesite. Bare rock surfaces predominate, but narrow ravines and lower canyon slopes have gravelly to rocky soils developed in and on them. Despite sparsity of soil, the area has a fairly good forest cover of pines. A small amount of glacial till occupies the higher valley section.

The reservoir was surveyed by reconnaissance methods. Four ranges were spudded at from 3 to 5 locations each, using as a base the contour map prepared by the Pacific Gas and Electric Company on a scale of 1 inch equals 300 feet in September and October 1929. Points for sediment measurement were located approximately by sighting on prominent shoreline features that could be recognized on an aerial photograph. The sediment depths were plotted along lines representing the length of the range and the area of sediment was computed. The average area on adjacent ranges multiplied by the distance between them was used to compute the sediment volume of segments. The computed volume for the entire lake was 22.2 acre-feet.

The sediment is silty fine sand near the dam and grades to coarse sand and gravel at the head of the lake. Soundings and comparison with the 1929 contour map permitted a check on depths of sediment. Distinction between present and pre-lake sediment was difficult in places, but the pre-lake bottom is solid granite everywhere except in a narrow channel section where the pre-lake surface is gravel and cobble. The survey is classified as having a fair degree of accuracy. The maximum sediment depth is 0.6 foot in the channel at the upper end. Most of the sediment is in the original stream channel. An estimated specific weight of 70 pounds per cubic foot was used because of the sandy and gravelly character of the sediment.

The sediment-production rate is extremely low. The unaltered primitive conditions of the drainage area limit sediment production to normal geologic erosion characteristic of areas that are virtually devoid of soils.

APPENDIX B

BASIS OF ESTIMATES OF SEDIMENTATION IN PROPOSED RESERVOIRS

Black Butte Reservoir. The geology and conservation surveys, made on a scale of 1 inch equals 1 mile, indicate that 92 percent of this drainage area should have a sediment-production rate comparable with the average of the East Park-Stony Gorge drainage area; whereas 8 percent should have a rate intermediate between those of the Magalia and Gerber areas. The specific weight of sediment is estimated to be higher than in the East Park and Stony Gorge Reservoirs owing to the apparent larger percentage of coarse sediment output below Stony Gorge dam and the greater extent and frequency of draw-down. The sediment-production rate was increased by 8 tons per square mile of net area to allow for sediment load passing Stony Gorge dam. The sediment-contributing drainage area excludes the areas above Stony Gorge and East Park Reservoirs.

Indian Valley Reservoir. No conservation survey was made, but the geology and topography indicates that the sediment-production rate should be comparable with that of the East Park-Stony Gorge drainage area. The probable similarity of sediment characteristics and operating conditions led to use of the average specific weight determined for Stony Gorge Reservoir.

Monticello Reservoir. No conservation survey was made, but the geology and topography of the area is generally comparable to that of the East Park-Stony Gorge drainage area. Rates of sediment production are known to be somewhat higher southward in the Bay region so that the figure used is believed to be conservative. The average specific weight of East Park-Stony Gorge sediments was used.

Iron Canyon Reservoir. Analysis of the drainage-area characteristics from conservation surveys made on a scale of 1 inch equals 1 mile, and from geologic maps indicates that the 52.3 percent of the area lying east of the Sacramento River should be apportioned in computing the gross sediment-production rates as follows: Misselbeck 9.3 percent; Faulke 3.9 percent; Blodgett 18.4 percent; mean of Magalia-Gerber 9.2 percent; East Park-Stony Gorge 50.2 percent; Pardee 9.0 percent. The 47.7 percent of the drainage area west of the Sacramento River was apportioned as follows: mean of Blodgett-Magalia 30.6 percent; mean of Stony Gorge-Magalia 10.1 percent; basalt-recent volcanic area at an estimated 135 tons per square mile 59.3 percent. Additional bed load present and moving in Dry Creek and Clear Creek was estimated to be equivalent to 130 tons per square mile for 45 percent of the net drainage, based on studies of rates of bed-load transportation on Big Dry Creek and observations on Cottonwood Creek. The weighted average annual rate equals 366 tons per square mile. An allowance of 9 tons per square mile of net drainage area for the sediment passing Shasta Dam brings the estimated total sediment inflow to 375 tons per square mile. The specific weight of sediment is assumed to be the same as in other major multiple-purpose

reservoirs of the Sierra front. The sediment-contributing drainage area excludes the area above Shasta Dam.

Big Bend Reservoir. No conservation survey was made on this drainage area. No extensive mining has been done during recent decades. Based on the similarity of geology, topography, and cover as observed by field inspection, the sediment-production rate is estimated to be between that of Pardee and Don Pedro Reservoirs. Specific weight is estimated to be the same as that of Exchequer Reservoir. The sediment-contributing drainage area excludes the area above Bucks, Butts Valley, and Almanor Reservoirs.

Bidwell Bar Reservoir. No conservation survey was made on this drainage area. No extensive mining has been done during recent decades. Based on the similarity of geology, topography, and cover as observed by field inspection, the sediment-production rate is estimated to be between that of Pardee and Don Pedro Reservoirs. The specific weight is estimated to be the same as that of Exchequer Reservoir. The sediment-contributing drainage area excludes the area above Lost Creek Reservoir.

New Bullards Bar Reservoir. The sediment-production rate is based on data from the present Bullards Bar Reservoir survey corrected for different trap efficiency and specific weight. It was assumed that mining activity and movement of old mining debris into the reservoir will continue at the same rate as during the period of sedimentation record. The conservation surveys indicate a low rate of land erosion. The major part of the sediment is derived from mining, roads, and lumbering activity. The specific weight of sediment is assumed to be the same as that determined for Exchequer Reservoir.

Garden Bar Reservoir. Sediment production is assumed to come from the drainage area of 127 square miles below Combie Reservoir plus the escape of sediment over the dam at Combie. The average escape rate was estimated from Figure 3 (after 1955) to be approximately 25 percent of the sediment inflow, based on the 1928-1931 sedimentation rate of approximately 50 acre-feet annually, during the first 50 years, 37.5 percent during the next 50 years, and 100 percent thereafter. The sediment-production rate for the area below Combie Dam is estimated to be the same as for the Folsom drainage area. The specific weight is assumed to be the same as that for Exchequer Reservoir.

Folsom Reservoir. The conservation survey of the drainage area indicates a sediment-production rate from land slopes intermediate between those of the Bullards Bar and Combie drainage areas. The Combie rate was taken as of the first three years of record (1928-1931) prior to extensive hydraulic-mining operations. The rate used assumes placer operations comparable to those since 1920 and continued movement of old mining debris, but no increased dredging and no hydraulic mining. The sediment-contributing drainage area excludes the area above the North Fork debris dam and above Loon Lake. The specific weight is assumed to be the same as for Exchequer Reservoir.

Nashville Reservoir. No conservation survey was made. In the absence of former extensive placer or hydraulic mining above the dam site, the sediment-production rate was assumed to be the same as that of the adjacent drainage area of Pardee Reservoir. The specific weight is assumed to be the same as for Exchequer Reservoir.

Hogan Reservoir. The conservation survey of the drainage area indicates a sediment-production rate intermediate between those of Pardee and Exchequer. The specific weight is assumed to be the same as for Exchequer Reservoir.

Farmington Reservoir. The conservation survey indicates a rate of sediment production slightly higher than that of the Salt Springs Valley Reservoir, which is less than that of Exchequer and Blodgett Reservoirs but higher than that of Pardee Reservoir. Topography above the proposed reservoir favors overbank deposition on the floodplain and deposits at the base of slopes, thus reducing the quantity of sediment reaching the reservoir.

The specific weight will be high because the reservoir basin will be dry except during and shortly after floods, thus exposing the sediment to drying and compaction. The sediment-contributing drainage area excludes the area above Salt Springs Valley Reservoir. The trap efficiency is estimated at 85 percent, based on the general characteristics of flood-control detention reservoirs as explained in the body of the report. The trap efficiency is estimated to be higher than for Burns, Bear, Owens, and Mariposa Reservoirs owing to the larger and longer reservoir area and the lower stream gradient through the storage basin.

New Melones Reservoir. The conservation survey indicates a rate of sediment production from land slopes comparable with the rate for Pardee Reservoir and lower than for Exchequer or Don Pedro Reservoirs. Presence of tailing dumps, which are in places cut by stream action, is the basis for increasing the estimated rate 8 tons per square mile per year over the Pardee rate. The specific weight is estimated to be the same as for Exchequer Reservoir. The sediment-contributing drainage area excludes the areas above Edna and Gertrude Lakes and Relief, Silver Valley, Highland, Lyons, and Strawberry Reservoirs.

New Don Pedro Reservoir. The rate of sediment production is assumed to be approximately the same as that determined from the survey of the existing Don Pedro Reservoir. The specific weight is estimated to be the same as that determined for Exchequer Reservoir. The sediment-contributing drainage area excludes the areas above Hetch-Hetchy Reservoir and Lake Eleanor.

Burns, Bear, Owens, and Mariposa Reservoirs. The drainage areas of these reservoirs were mapped as one unit. The surveys indicate rates higher than for Exchequer and Don Pedro and only slightly less than the rate determined from Davis Reservoir. Drainage-area inspection indicates

that the rate should be somewhat higher for Mariposa than for other streams because of stream-bank cutting and the extent of gullied areas.

The trap efficiency is estimated at 75 percent, based on general characteristics explained in the report. The specific weight will be high as the sediment will be exposed to thorough drying and compaction.

Buchanan Reservoir. No conservation survey was made. General inspection of the area and its geologic characteristics indicate a sediment-production rate between those of Don Pedro and the Merced group of reservoirs. The specific weight is estimated to be the same as for Exchequer Reservoir.

Hidden Reservoir. No conservation survey was made. General inspection of the area and its geologic characteristics indicate a sediment-production rate between those of Don Pedro and the Merced group of reservoirs. The specific weight is estimated to be the same as for Exchequer Reservoir.

Pine Flat Reservoir. The conservation survey indicated a sediment-production rate intermediate between those of Pardee and Exchequer Reservoirs. The sediment-contributing drainage area excludes the area above Hume Lake. The specific weight of sediment is assumed to be the same as that of Exchequer Reservoir.

Terminus Reservoir. The conservation survey indicated a sediment-production rate higher than those of Don Pedro and Davis and higher than that of Success, which is slightly above the rate for Davis. The specific weight of sediment is assumed to be the same as that of Exchequer Reservoir.

Success Reservoir. The conservation survey indicated a sediment-production rate higher than that of Don Pedro and slightly above that of Davis. The specific weight of sediment is assumed to be the same as that of Exchequer Reservoir.

Isabella Reservoir. The conservation survey indicated a sediment-production rate higher than that of Exchequer and lower than that of Don Pedro. The specific weight of sediment is assumed to be the same as that of Exchequer Reservoir.

Big Dry Reservoir. The conservation survey indicates a somewhat higher rate of sediment production than from the Success and Terminus drainage areas. The rate from the land slopes is estimated at 425 tons per square mile annually. An excessive quantity of bed load moving down the channel indicates a supply of sediment from sources not otherwise evaluated in the conservation survey. These sources, which appear to be mainly dissection of an old alluvial fan, yield an estimated equivalent of 125 tons per square mile out of an estimated total bed-load movement of 264 tons per square mile annually. Thus the total rate of sediment production is estimated to be 550 tons per square mile. The trap efficiency is estimated at 90 percent based on the relatively coarse grade of the

material comprising the sediment load and on the manner of operation which provides for diversion of the flows that transport most of the load across the broad floodplain area of the basin with sufficient detention, in general, to rather thoroughly desilt the flow with relatively little opportunity for subsequent scouring. The specific weight is estimated at 85 percent because the sediment will be exposed to thorough drying and compaction every year.

Friant Reservoir. The rate of sediment production is based on 250 tons per square mile as estimated for the drainage area above Kerckhoff Reservoir, and 325 tons per square mile for the net drainage area between Friant Dam and Kerckhoff Dam, based on the observed similarity of drainage-area characteristics to the area above Hidden Reservoir. The sediment-contributing drainage area above Kerckhoff Dam was taken as 1,125 square miles (the gross area of 1,460 square miles less the areas above Crane Valley Reservoir (55 sq. mi.), Huntington Reservoir (79 sq. mi.), Florence Lake (171 sq. mi.), and Shaver Lake (30 sq. mi.)). It is assumed that Kerckhoff Reservoir, Manzanita Lake, Dam No. 6, and other forebay and diversion dams, because of their low capacity/drainage area ratios and frequent flushing operations, will not in the future permanently trap any sediment. The average sediment-production rate of the net contributing area of 1,346 square miles above Friant Dam is, therefore, 262 tons per square mile. The reservoir capacity reported by the U. S. Bureau of Reclamation is 550,000 acre-feet. The specific weight is estimated to be the same as for Exchequer Reservoir.

Literature Cited

(1) Barnes, F. F., Kraebel, C. J., and LaMotte, R. S.
Effect of Accelerated Erosion on Silting in Morena Reservoir, San Diego County, California. U. S. Dept. Agr. Tech. Bul. 639. 21 pp., illus. Washington, U. S. Govt. Print. Off., 1939.

(2) Bermel, K. J., and Sanks, R. L.
Model Study of Brown Canyon Debris Barrier. Amer. Soc. Civ. Eng. Proc. 72:613-628, May 1946.

(3) Brown, C. B.
Discussion of "Sedimentation in Reservoirs" by B. J. Witzig. Amer. Soc. Civ. Engin. Trans. 109:1080-1086. 1944.

(4) Brown, C. B.
Rates of Sediment Production in Southwestern United States. U. S. Soil Conserv. Serv., SCS-TP-58. 40 pp., illus., processed. Washington, D. C., Jan. 1945.

(5) Brown, C. B.
Report on the Sedimentation Surveys of Little Rock Reservoir, Los Angeles County, California. U. S. Soil Conserv. Serv., Spec. Rpt. 6. 11 pp., illus., processed. Washington, D. C., Dec. 1943.

(6) California. Department of Public Works, Division of Water Resources.
Dams under Jurisdiction of the State of California. July 1, 1941.

(7) Eakin, H. M.
Silting of Reservoirs. U. S. Dept. Agr. Tech. Bul. 524. Rev. by C. B. Brown. 168 pp., illus. Washington, U. S. Govt. Print. Off., 1939.

(8) Einstein, H. A.
Bed-Load Transportation in Mountain Creek. U. S. Soil Conserv. Serv., SCS-TP-55. 54 pp., illus., processed. Washington, D. C., Aug. 1944.

(9) Gilbert, G. K.
Hydraulic-Mining Debris in the Sierra Nevada. U. S. Geol. Survey Prof. Paper 105, 1917.

(10) Hall, L. S.
Discussion of "Sedimentation in Reservoirs" by B. J. Witzig. Amer. Soc. Civ. Engin. Trans. 109:1093-1098. 1944.

(11) Hall, L. S.
Silting of Pardee Reservoir. Hydrographic Div. East Bay Municipal Utilities District, Spec. Rpt. P-4, 1944. [Unpublished]

(12) Lane, E. W., and Kennedy, J. C.
A Study of Sedimentation in a Miami Conservancy District Reservoir. Amer. Geophys. Union Trans. (1940)21, pt. 2:607-612.

(13) Lippincott, J. B.
Silting of the LaGrange Reservoir. Engin. Record 61(15):508. April 16, 1910.

(14) Meadowcroft, N. F.
Investigation of Sedimentation at Kerckhoff Reservoir and Dam No. 6, Sierra National Forest. U. S. Forest Service Regional Office, San Francisco, Dec. 1939 (with supplement by H. J. Fittinger, Dec. 1943). [Unpublished]

(15) Norton, E. A.
Soil Conservation Survey Handbook. U. S. Dept. Agr. Misc. Pub. 352, 39 pp., illus. 1939.

(16) Troxell, H. C., and others
Floods of March 1928 in Southern California. U. S. Geol. Survey Water-Supply Paper 844, 1942.

(17) United States Department of Agriculture
Atlas of American Agriculture - Natural Vegetation. 26 pp., illus. 1924.


U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
SACRAMENTO - SAN JOAQUIN
DRAINAGE BASINS
CALIFORNIA
To accompany report on RESERVOIR SEDIMENTATION IN THE SACRAMENTO - SAN JOAQUIN DRAINAGE BASINS, CALIFORNIA, by Carl B. Brown and Eldon M. Thorp, Special Report No. 10, Sedimentation Section, Office of Research, Soil Conservation Service, July 1947.
LEGEND
Major drainage basin
Minor drainage basin
Isohyetals of average annual precipitation
Major reservoir
Minor reservoirs surveyed
Drainage areas controlled by upstream reservoirs and excluded in sediment production computations
FOLSOM DAM SITE
Dam sites of flood control or multiple-purpose reservoirs proposed by the Corps of Engineers, War Department, in comprehensive survey report dated 1 February 1945
15 0 15 30 45 Miles
NOTE. DATA FROM MAPS SUPPLIED BY THE SACRAMENTO DISTRICT, CORPS OF ENGINEERS, WAR DEPARTMENT.
OREGON
CALIFORNIA
NEVADA
CALIFORNIA
PACIFIC OCEAN
CASCADE RANGE
COAST RANGE
SIERRA NEVADA
SHASTA RESERVOIR
IRON CANYON DAM SITE
BLACK BUTTE DAM SITE
BIG BEND DAM SITE
BIDWELL BAR DAM SITE
INDIAN VALLEY DAM SITE
GARDEN BAR DAM SITE
NORTH FORK DEBRIS DAM SITE
FOLSOM DAM SITE
MONTICELLO DAM SITE
NASHVILLE DAM SITE
FARMINGTON DAM SITE
BURNS DAM SITE
BEAR DAM SITE
OWENS DAM SITE
MARIPOSA DAM SITE
BUCHANAN DAM SITE
HIDDEN DAM SITE
BIG DRY DAM SITE
PINE FLAT DAM SITE
TERMINUS DAM SITE
SUCCESS DAM SITE
ISABELLA DAM SITE
SACRAMENTO
STOCKTON
SAN FRANCISCO
OAKLAND
FRESNO
BAKERSFIELD
Redding
Red Bluff
Chico
Marysville
Merced
Reno
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